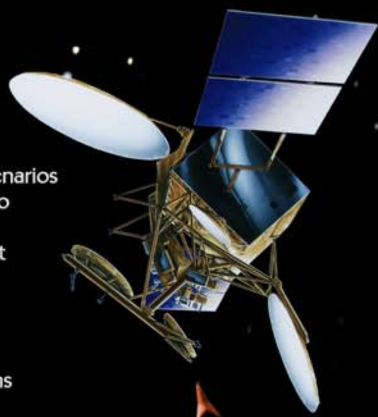
National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

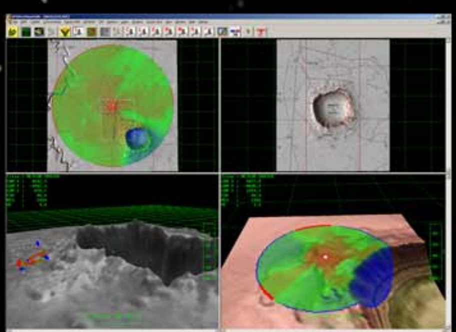
Explore. Discover. Understand.

Surface Networking for Space Exploration Applications

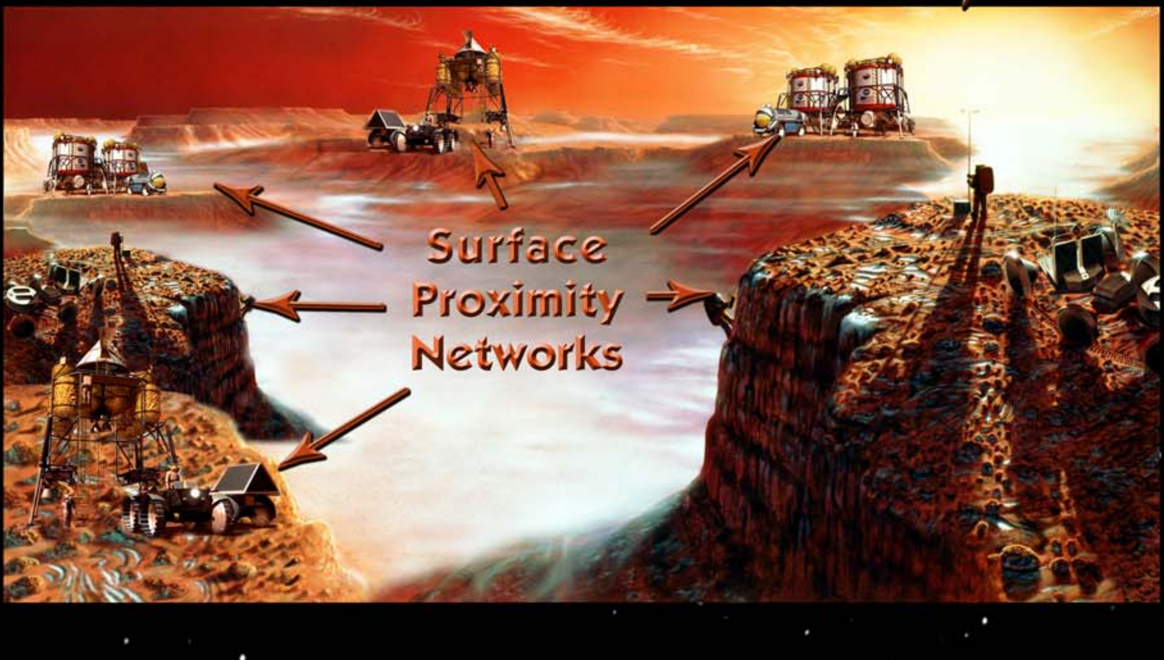
Glenn Research Center's efforts will focus on the characterization, evaluation, development, and extension of commercial-off-the shelf (COTS)-based wireless protocols and communication technology to support surface planetary exploration.



- Conduct requirements and analysis of existing and emerging planetary exploration scenarios
- Develop surface wireless network architectures that include integrated COMM/NAV to support associated reference missions
- Evaluate existing and emerging wireless and adhoc protocols for extensibility to meet reference surface network scenarios
- Create software tools to aid in the evaluation of protocols and hardware
- Conduct integrated smart antenna subsystem analysis and tradeoff study to support surface network scenarios
- Evaluate networks and protocols and surface propagation using computer simulations
- Identify advanced signal processing techniques to mitigate severe degradation in multipath environments
- Design, develop, and emulate integrated communication and navigation network systems



Visualization of Measured Data for a Wireless Mesh Network



National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Antenna Technology and Capabilities

Large Aperture Inflatable Antennas

Space Applications

4- by 6-m inflatable offset parabolic membrane antenna test in GRC near-field facility

4- by 6-m inflatable offset parabolic membrane antenna inflation test (human in the background)

Deep-space relay station concept

Overhead photograph of 4- by 6-m inflatable reflector in GRC near field facility

Backup 2-m inflatable Cassegrain reflector for ISS Ku-band system

Surface Applications

Low-cost tracking ground station experiment in collaboration with Goddard Space Flight Center planned for May 2005

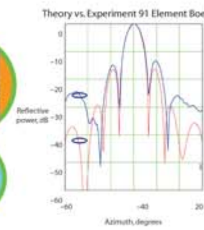
2.5-m inflatable membrane antenna in inflatable radome for ground applications

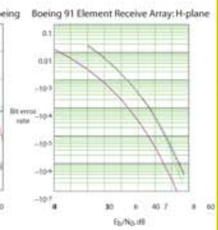
Goals:

- Develop large, lightweight reflector antennas with areal densities <0.75 kg/m2, for Lunar, Mars, and deep-space relay exploration applications.
- Develop rigidization techniques (e.g., ultraviolet curing) to eliminate the need for makeup inflation gas.
- Demonstrate a ratio package to deploy volume greater than 1:7
- Demonstrate quick deployment of large apertures for ground-based and planetary surface applications.

Antenna Systems Technology

Array-Based System Characterization





- Improve the performance of array based systems by developing techniques to measure end-to-end system interaction and mitigate the degrading effects of transmitting high rate data through high frequency phased array antennas.
  - Bit error compensation techniques
  - Alternative subsystem designs
  - Optimal modulation schemes

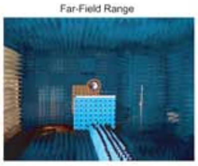
Antenna Metrology and Characterization Facilities

GRC Antenna Facilities

Compact Range

- Antenna and RCS measurements
- 12- by 10- by 26- foot anechoic chamber test volume
- 6- by 6- foot cross section, offset parabolic reflector, 3- by 6- foot cylindrical quiet zone
- Frequency range: 2 to 36 GHz

Far-Field Range



- Measurement of small microwave antennas
- 18- by 12- by 30- foot anechoic chamber test volume
- Frequency range: 2 to 40 GHz

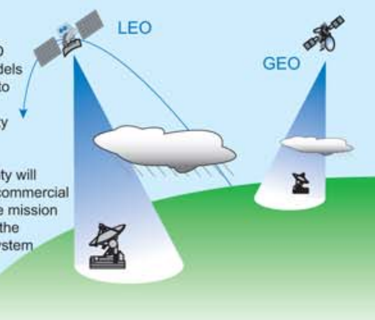
Near-Field Range

- Measurement of mechanically large microwave antennas
- 40- by 40- by 60- foot test volume
- 6.7 by 6.7-m vertical scan plane
- 15-ton capacity AS/EL positioner
- Removable sidewall, bridge cranes, and loading ramp assist setup
- Frequency range: 2 to 40 GHz

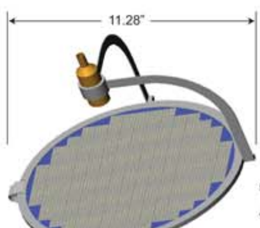
Ka-Band Propagation Measurement and Analysis

Goals:

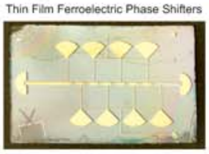
- Develop and evaluate LEO and GEO propagation models that will enable designers to reduce the uncertainty of Ka-Band system availability predictions.
- This reduction in uncertainty will enable NASA, DOD, and commercial mission planners to reduce mission cost by not overdesigning the communication network system link margins.

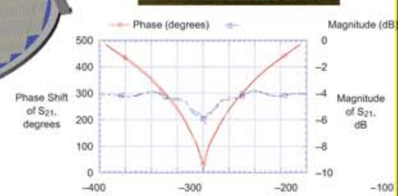


Ferroelectric Reflectarray Antenna



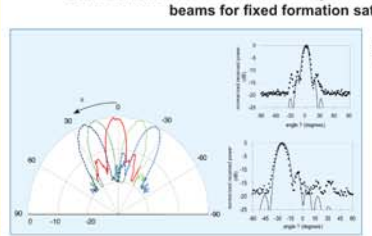
Thin Film Ferroelectric Phase Shifters

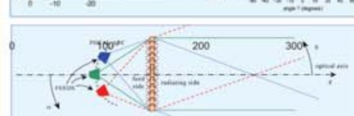




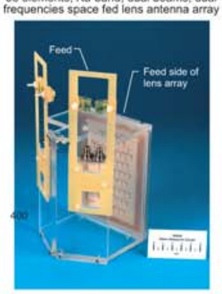
Space Fed Lens Array Antennas

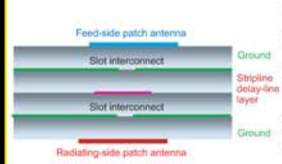
Goal: Demonstration of antenna arrays with independent multiple beams for fixed formation satellites





56 elements, Ka-band, dual beams, dual frequencies space fed lens antenna array



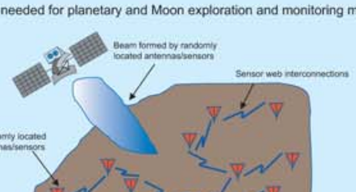


Specifications for multilayer arrays

- At least two simultaneous beams, 10° beamwidth
- Up to 6 beams
- Dual polarization
- Dual frequency (25.5 and 27.5 GHz) and full duplex
- Narrowband around each carrier
- Fine beam tuning (5°—half a beamwidth)
- Distributed amplifiers for full-duplex T/R

Miniaturized Reconfigurable Antenna for Planetary Surface Communications

- Develop electrically small (miniaturized) antennas with moderate bandwidths for planetary surface communications between remote sites sensors or orbiters
- The technology is intended to enable low-risk sensing and monitoring missions in hostile planetary and/or atmospheric environments
- These antennas are needed for planetary and Moon exploration and monitoring missions



Collaboration with University of Illinois

Point of Contact

Félix A. Miranda, Ph.D., Branch Chief, Antenna, Microwave, and Optical Systems Branch

Phone: 216–433–6589, Fax: 216–433–3478

E-mail: Felix.A.Miranda@nasa.gov

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Glenn Research Center Software Defined and Reconfigurable Radio Technology

Objectives

- Near term: Define an open architecture to provide software portability and reuse, scalability, and hardware and software independence
- Mid term: Develop a test-bed for architecture development, testing, and evaluation
- Long term: Perform a flight demonstration in a relevant mission class

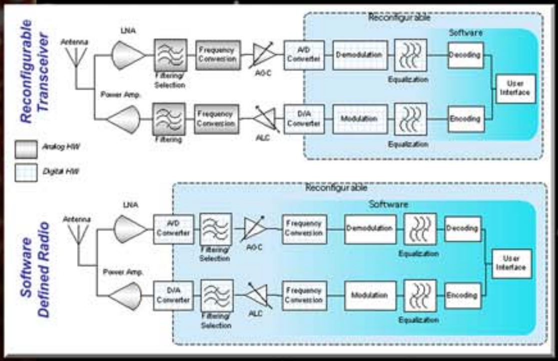
Top Challenges for GRC and Its Partners in This Research

- Achieve desired SDR flexibility required by mission class while minimizing the spacecraft resources (i.e., mass, power, and volume)
- High-density digital devices required for high data rates for the space environment

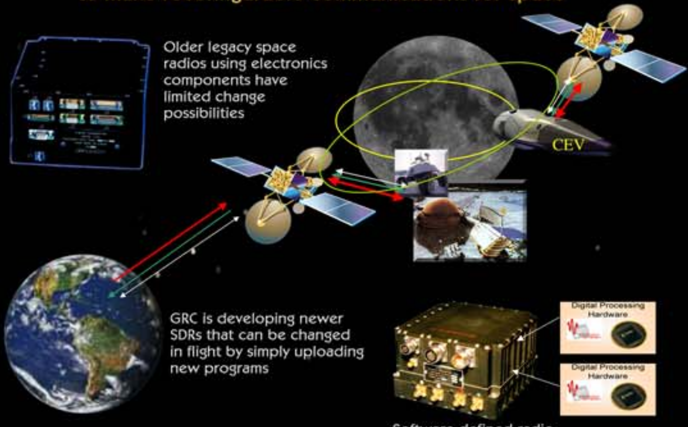
GRC is seeking partners in this exciting, emerging area of research!

A functioning Software-Defined (SDR) Radio in GRC's Software-Defined and Reconfigurable Radio Laboratory (Feb 2005).

Reconfigurable transceivers and SDRs are the future of telecommunications!



GRC is leading the progression of SDR from electronic components to software to make reconfigurable communications for space



Software defined radio

Advanced Space Suit Technologies

Objectives

- Understand the communications, avionics, informatics (CAI), sensor, and power system requirements for advanced space suits
- Develop engineering prototype hardware for infusion into flight program
- Develop flight articles for human missions back to the Moon (Spiral 2) and to Mars (Spiral 4 and 5)

Top Challenges for GRC and Its Partners in This Research

- Safety, mass, volume, performance, flexibility, and modularity of advanced space suit technology; and high-performance communications and computing hardware and software
- Health monitoring of humans and suits

GRC has the Agency lead role for CAI and power for advanced space suits.
GRC is seeking partners in this exciting, emerging area of research!

- GRC is revamping the radio equipment used on modern space suits.
- GRC is also working to eliminate the head-gear worn by astronauts and "clean up" space suit audio using advanced signal processing technology.

Partner with GRC to study new ways to collect, process, transfer, organize, and display information obtained during extravehicular activities (EVA informatics).

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

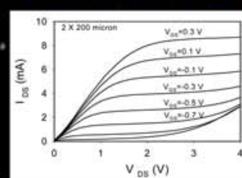
Explore. Discover. Understand.

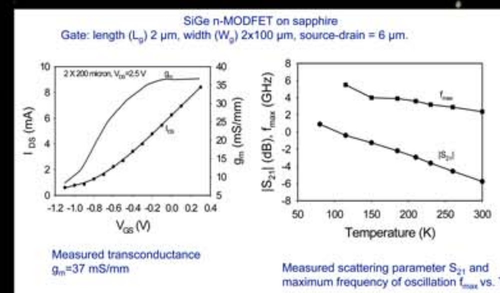
Semiconductor Device Technology and TWT Studies

Structures for SiGe/Si n-MODFET on Sapphire

- 5-μm linearly graded buffer layer
- 0.6-μm virtual substrate
- 10-nm conducting channel (tensile-strained Si layer)
- Sb concentrations: 2 and 4×10^{12} cm^{2}

Measured I-V characteristics of n-MODFET Gate length 2 μm and width 2 by 100 μm, source-drain = 6 μm





High-Temperature SiC Wireless Technology

High-temperature probe station and instrumentation

Technology Advancement

- System enables on-wafer measurement of active and passive RF/microwave devices for wireless applications.
- Temperature control of device under test from room temperature to 600 °C and above.
- Passive devices have been characterized at temperatures up to 540 °C.

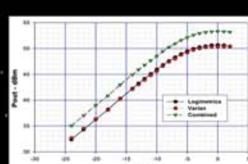
Wafer probe technology enables fast and accurate characterization of devices and circuits, leading to high-temperature wireless technology.

Microwave probe with heat shielding

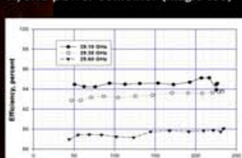
Heater stage with RF/microwave probes

Traveling Wave Tube (TWT) Power Combiner

Hybrid power combiner (magic tee)

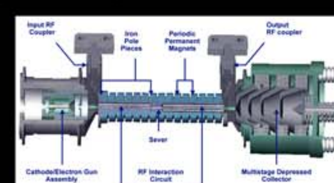


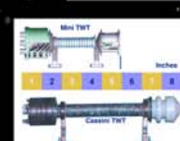
Combiner output power (dBM)



Combiner efficiency percent

High-Efficiency 32-GHz Miniaturized TWT

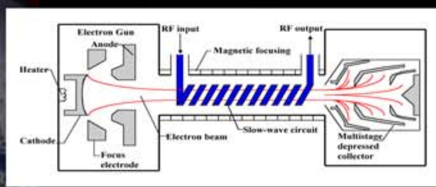


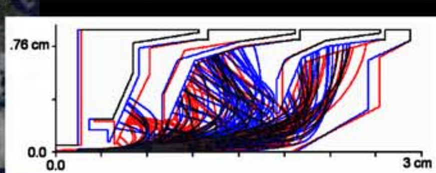


	Cassini	MiniTWT (estimated)
Length	20 cm	12 cm
Mass	400 gm	200-300 gm
RF Power	10 W	20-25 W
Efficiency	41%	55%

Comparison of Mini TWT and Cassini TWT

Multistage Depressed Collector Optimization





Electron trajectories in 4-stage depressed collector

- Overall efficiency = (RF output power)/(beam power—recovered power)
- Created TWT collector optimization algorithm
  - Based on simulated annealing
  - Solution of Poisson's equation for trajectories
  - Determines voltages and geometry

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Engineering Systems Division at Glenn Research Center

Provides a unique blend of engineering capabilities and resources unmatched within NASA or industry.

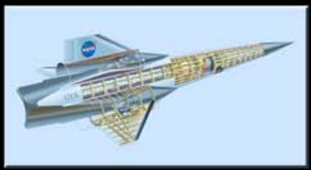
Goal
- Identify and mature high-payoff emerging technologies to enable new flight and ground aerospace applications.
- Support commercialization of key technologies.

Multidisciplinary organization providing advanced engineering, design, and rapid prototyping expertise in the following areas:
- Advanced Concepts Development
- Avionics and Controls
- Flight Software
- Design/Drafting
- Optics and Acoustics
- Fluid Systems Design
- Turbomachinery Design
- Advanced Prototyping
- Electromagnetic Interference (EMI)/Compatibility
- Instrumentation/Diagnostics
- Structural Dynamics
- Structural Design and Analysis
- Thermal Design and Analysis
- Systems Engineering and Integration
- Microsensor Technology
- Mechanical Micromachining
- Laser-Engineered Net Shaping

Wide variety of programs supported at NASA:
- Microgravity
- Aerospace Base
- Space Exploration
- Ultra-Efficient Engine Technology
- Aviation Safety
- Space Power and Propulsion
- Space Communications

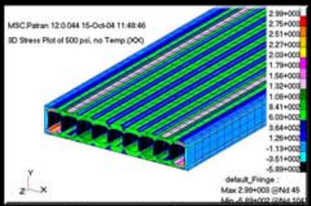
Examples of areas of expertise:
- Thermal and Fluids Engineering
  - Plume and Aerodynamic Heating
  - Combustion and Mixing
  - Boundary Layer Flows
  - Cryogenic Systems
  - Computational Fluid Dynamics
  - Space Thermal Radiation Analysis
- Structural Design and Analysis
  - Nonlinear Finite Element Modeling
  - Large Space Structures Design
  - Lightweight Cryogenic Pressure Vessels Design
  - Composite and Ceramic Material Testing
  - Fracture Mechanics
  - Crack Propagation
  - Embrittlement and Flutter
- Structural Dynamics and Acoustics
  - Improved acoustic treatments for Titan IV/Cassini
  - Vibration Laboratory used to flight qualify virtually every microgravity payload from NASA Glenn
- Electrical and Electronics Design
  - World-class EMI Facility and state-of-practice
  - Concurrent circuit and thermal simulation with layout capabilities
- Controls
  - Attitude Control Algorithms for Advanced Communications Technology Satellite (ACTS)
  - Guidance control systems for Atlas, Titan, and Centaur
  - Compact dampers for repulsive magnetic bearings for flywheels
  - Active combustion control to suppress high-frequency combustion instabilities in jet engines

Examples of projects to which Engineering Systems Division has contributed, ranging from conceptual design to final hardware, are shown in the right-hand column:

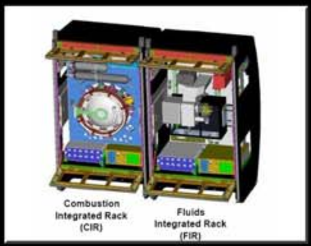


GTX vehicle (Rocket-Based Combined Cycle)

1/3 Scale Model of GTX Vehicle in the 10- by 10-Foot Supersonic Wind Tunnel

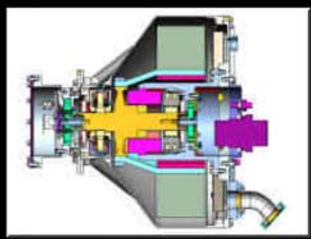


Stress plot for ceramic matrix composite (CMC)-cooled panel under pressure loads

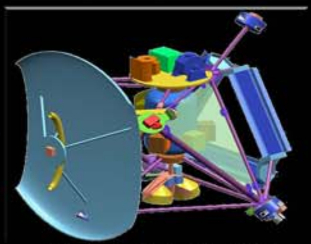


Fluid Combustion Facility (FCF) racks for Space Station

16-channel 500-KHz Acoustic phased array in metal housing



Generation 3 Flywheel Module with magnetic bearings for energy storage in space



Outer Planetary Target Orbiter (OPTO) Spacecraft Concept

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

GRC Engineering Verification Laboratories

CAPABILITIES

- Prototype and flight hardware qualification, acceptance, and workmanship testing, modal testing, and analytical correlation
- Low acceleration level microgravity testing
- Ground-based simulator for evaluation exercise countermeasure devices
- Acoustic emissions testing in full anechoic and hemianechoic configuration to meet International Space Station (ISS) acoustic emissions requirements
- Isolation of electronic equipment to allow measurement of emissions
- Electric field reverberation testing

ACOUSTICAL TESTING LAB (ATL)

- Acoustic emissions testing in full anechoic or hemianechoic configuration
- Sound power determinations per ISO 3744
- Scanning sound intensity measurements and other diagnostic techniques


Acoustical Test Lab

ELECTROMAGNETIC INTERFERENCE (EMI) LAB

- MIL–461C and NASA-derived test methods
- Automated susceptibility testing
- Reverberation test facility, per MIL–461E
- Design of customized tests
- Two Test Chambers provide maximum versatility
  - Accommodates small and large equipment Under tests (EUTs)
  - Testing of multiple customers concurrently for high flow rate


Electromagnetic Interference Lab

MICROGRAVITY EMISSIONS LAB (MEL)

- Six-degree-of-freedom inertial force characterization through ground-based testing
- Microgravity (10^{-6}) level of acceleration measurement testing
- Self-excitation vibration testing of ISS Space Rack and Aerospace Propulsion Components
- Ground-based simulator for evaluation of astronaut exercise countermeasure devices


Microgravity Emissions Lab

STRUCTURAL DYNAMICS LAB (SDL)

- Prototype and flight hardware qualification
- Acceptance and workmanship testing
- Modal testing and analytical correlation
- In situ testing and characterization


Structural Dynamics Lab

STRUCTURAL STATIC LABORATORY (SSL)

- Performs testing to verify the structural integrity of space flight hardware
- Equipped with a 20 000-lb tensile test machine that can develop mechanical properties in metallic and composite coupons and adhesive and weld joints at up to 1300 °F
- Verifies modes of failure when the design is subjected to simulated service loads of up to 60 000-lb on three axes, simultaneously
- Structural testing capabilities include
  - Tensile, compression, bending, creep, and creep fatigue
  - High- and low- cycle fatigue testing
  - Complex tests such as multirate ramps and block loading


Structural Static Lab

EXERCISE COUNTERMEASURES LAB (ECL)

- Capabilities: Treadmill Vibration Isolation System (TVIS), Cycle Ergometer With Vibration Isolation System (CEVIS), and Interim Resistive Exercise Device(IRED) exercise modalities and crew subject load devices(SDLs) may be evaluated for biomechanical loading in a ground-based simulator, which simulates on-orbit exercise, and locomotion in reduced g (Moon, Mars)
- Treadmill with integrated force plate and SLD assembly ride on frictionless air-bearing table, 1 or 3 degrees of freedom motion possible
- Variably compliant isolators simulate ISS exercise countermeasure device dynamics
- Customers: NASA-wide Human Health and Countermeasures researchers


Exercise Countermeasures Lab

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

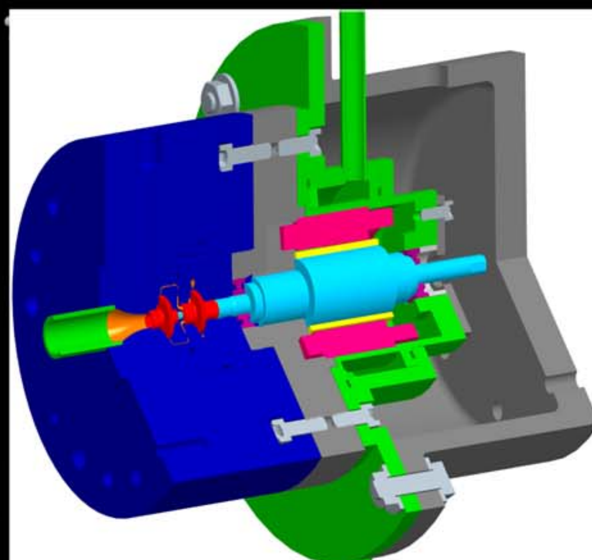
Engineering Systems Division

Satellite Propellant Pump Demonstrator

A demonstration satellite fuel delivery pump was designed and manufactured to supply hydrazine fuel to on-orbit thrusters. Pump would replace a pressurized fuel tank thereby greatly reducing overall spacecraft weight. Miniature size allows fitment into small satellite systems (impeller diameter ~0.5 in. A canned motor design integrates electric motor and shaft to achieve compact envelope.

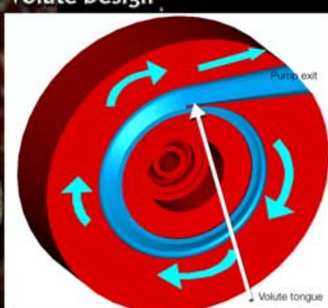
Static de-Swirl Vane Flow Path

Key vane flow parameters:
- Blade count: 16
- Area over diameter ~0.007
- Area ratio ~4.3 to 1 between entrance and exit
- Cone angle (conical diffuser) ~ 5°
- Maintain smooth area expansion through vanes



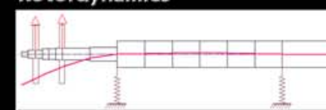
Pump Performance Parameters:
125 psi per stage pressure rise at 57000 rpm, flow rate 1 gpm, 57 percent pump efficiency

Volute Design



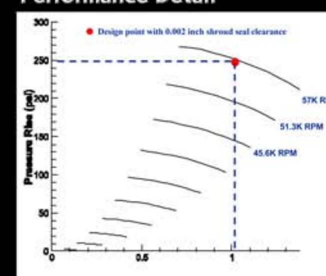
Key volute flow parameters:
- Area over diameter ~0.007
- Area ratio ~8.33 to 1 from start to finish
- Exit diffuser cone angle of ~5° and 4 to 1 area ratio
- Maintain linear area expansion for constant average velocity

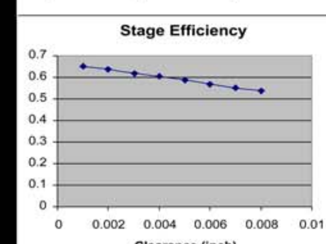
Rotordynamics



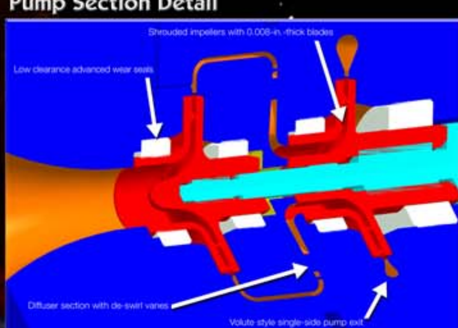
Critical speed analysis using dyrobes
- Dynamic analysis used to determine rotor critical speeds
- Modeled using simulations of bearings, impellers, and shaft

Performance Detail





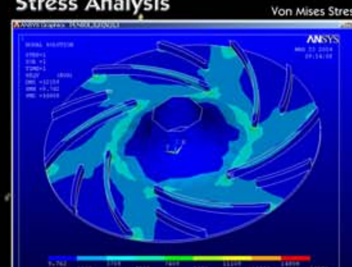
Pump Section Detail



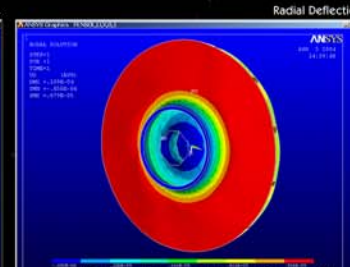
Two-stage cetrifugal style pump
- Shrouded impellers with 0.008-in.-thick blades
- Low clearance advanced wear seals
- Diffuser section with de-swirl vanes
- Volute style single-side pump exit

Stress Analysis

Von Mises Stress

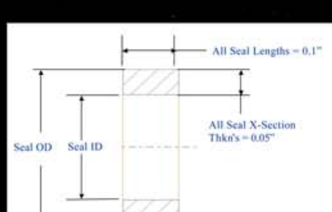


Radial Deflection



Three dimensional finite element analysis using ansys
- Determined impeller stress and deflection
- Hand calculations used for verification

Pump Seal Design



American High Performance Seals details
- Permachem 5600 high-strength low-friction wear seal material
- Interference fit using liquid nitrogen shrink installation
- Machinable to tight tolerances for minimal clearance after installation

Manufacturing

- Machining and assembly done by Tri-Models, Inc.
- Seals designed and fabricated by American High Performance Seals
- Electric motor and pump shaft furnished by Emoteq, Inc.

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

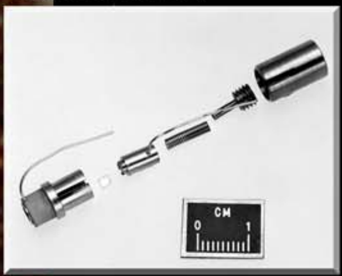
Engineering Systems Division

Prototype Development and Metals Technology Branches

Technologies

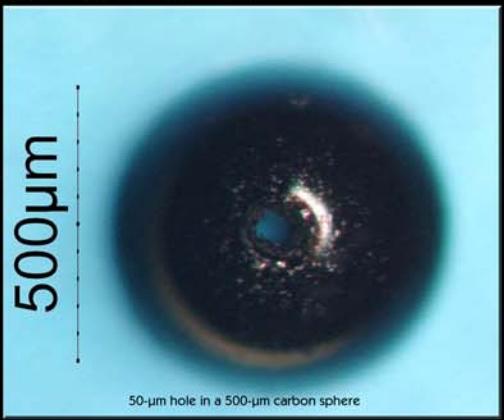
Fabrication

Cathode Assembly



Exotic materials such as molybdenum, tungsten, and tantalum used for electron gun

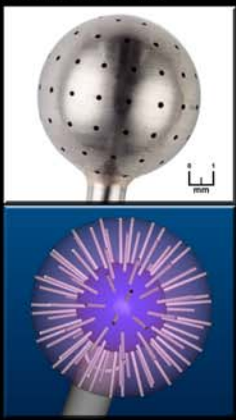
Laser Drill Carbon Sphere



Microgravity combustion experiments were conducted with a variety of porous carbonaceous particles to determine

- Oxidation rate
- Flame standoff distances
- Surface temperatures

Stainless Burner

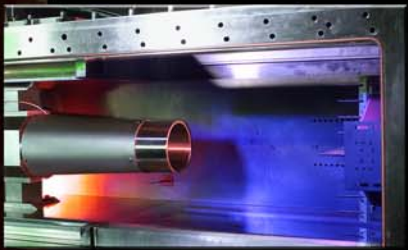


Made to create a bouyant flame in microgravity. A 6.35-mm-diameter sphere contains ninety 0.2-mm- diameter holes as depicted in solid model.

Instrumentation

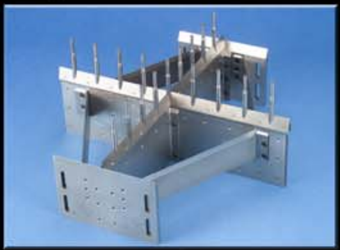
Pressure, Temperature, and Strain Sensing

1- by 1- Foot Supersonic Wind Tunnel



- Supports pulse detonation engine research
- Modular design allows for quick onsite replacement of pitot probes
- Each probe incorporates dynamic and steady-state pressure sensors

1- by 1- Foot Calibration Rake



Airflow measurement hardware. Design allows for ease of repair that minimizes test schedule impact.

Rapid Prototyping

The term "rapid prototyping" (RP) refers to any of a number of platforms that "grow" three-dimensional objects layer-by-layer in a sequential fashion. The key advantages of these processes is the ability to rapidly produce highly complex models with exceptional aesthetic qualities. Each platform consumes different types of plastics or metals based on material requirements and utility of the part. The RP Lab at Glenn operates four platforms: Selective Laser Sintering, Stereolithography, Direct Material Deposition System, and Fused Deposition Modeling, which all utilize this unique additive process.

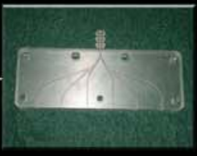
Metal




Polymers







National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Plum Brook Station

Where Space Comes Down to Earth

Plum Brook's world-class facilities are capable of emulating environmental conditions like those found on Earth, in low Earth orbit, on planetary surfaces, or in deep space.

SPF Space Power Facility

The Space Power Facility (SPF) is the world's largest space environmental simulation chamber, measuring 100 ft in diameter by 122 ft in height. This cathedral of a facility was designed to test nuclear and nonnuclear space hardware, fully simulating the low-Earth-orbit and deep-space environment except for gravity.

CTC Cryogenic Test Complex

The Cryogenic Test Complex (CTC) encompasses the 25-ft-diameter chamber of the Cryogenic Propellant Tank Research Facility (K-Site), as well as a new, state-of-the-art facility for research, development, and qualification of cryogenic materials, components, and systems.

B-2 Spacecraft Propulsion Research Facility

The Spacecraft Propulsion Research Facility (B–2) is the world's only facility capable of hot firing full-scale, upper-stage launch vehicles and rocket engines under simulated high-altitude or space conditions.

HTF Hypersonic Tunnel Facility

The Hypersonic Tunnel Facility (HTF), originally designed to test nuclear thermal rocket nozzles, is presently configured as a hypersonic (Mach 5, 6, and 7) blowdown, nonvitiated (contamination-free), freejet, or direct-connect facility to test large-scale, hypersonic, air-breathing propulsion systems.

National Aeronautics and
Space Administration

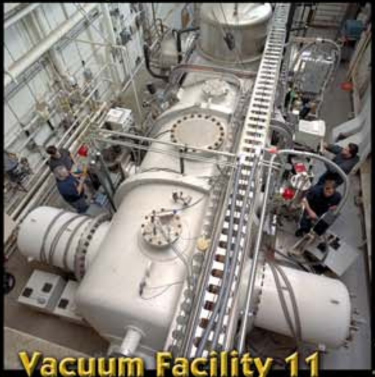
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Vacuum Facilities

Vacuum Facility 6

Vacuum Facility 8



Vacuum Facility 11

Vacuum Facility 5

Ion Engine

Hall Thruster

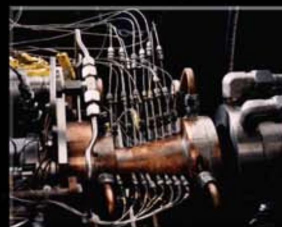
National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

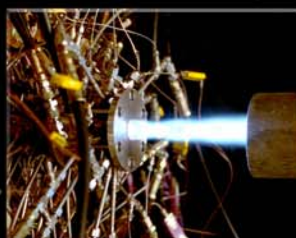
Explore. Discover. Understand.

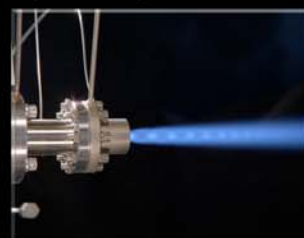
Research Combustion Laboratory

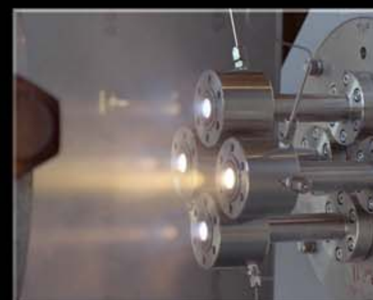
Low-thrust altitude testing of small chemical thrusters and rocket engine components



Low-flow chemical propulsion ignition studies







High-temperature, high-heat-flux materials testbed

General purpose sea-level combustion stands for research and evaluation of chemical rocket components

Heated Tube Facility

Heat transfer, material compatibility, and fuel coking studies for fuel-cooled rocket engine components

SMiRF

- Vacuum test facility for cryogenic handling, long-term storage, and spacecraft component research
- Capable of simulating the space shuttle launch pressure profile

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Fuel Cell Test Facilities

Fuel Cell Test Laboratory
Building 334

The Fuel Cell Test Laboratory is equipped with three separate cells with identical capabilities designed to test a variety of fuel cells ranging from 1- to 125-kW power output.

Fuel Cell Laboratory
Building 16

- The building 16 fuel cell test bed is equipped to test H_2/air fuel cells and hybrid power systems ranging in size from single cells up to 10 kW.
- Defined power load profiles are applied via electronic loads as well as an electric motor/dynamometer combination.

Regenerative Fuel Cell Facility
Building 135

The Integrated Equipment Assembly, shown here, combines a 0- to 5-kW fuel cell stack and a 0- to 15-kW electrolyzer stack into a closed loop hydrogen/oxygen regenerative fuel cell test bed.

Research Combustion Lab
24–C

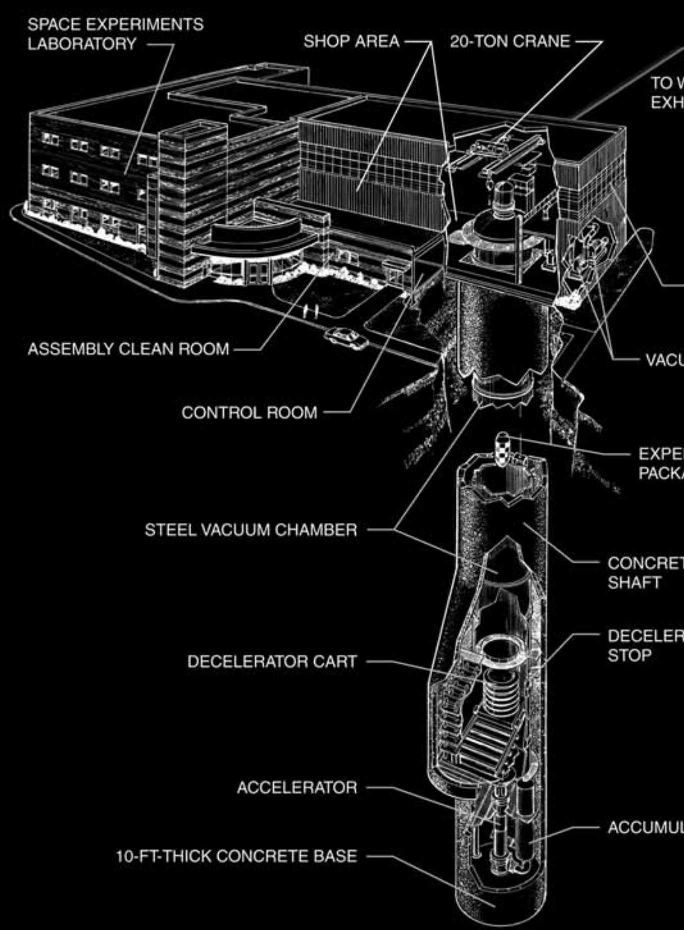
- 0- to 5.25-kW H_2/O_2 fuel cell test stand
- 0- to 15-kW electrolyzer test stand

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Zero-Gravity Research Facility



BOTTOM OF SHAFT 510 FT BELOW GROUND LEVEL

Positioning a drop vehicle on top of the vacuum chamber

Drop vehicle with Gas Jet Combustion Experiment onboard

Drop vehicle with Effect of Electric Fields on Flames Experiment onboard

Retrieving the drop vehicle after a test in the Zero-G Facility

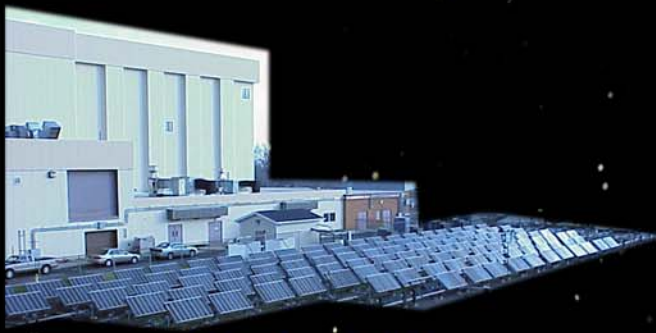
Drop vehicle entering the decelerator cart after 5.18 sec free fall

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Power Systems Facility (PSF)



Solar Array Field

- 30 kW at 160 V maximum
- 80 array strings at 2.5 A/160 V

Power Sources

- 500 kW of direct current power up to 600 V
- 90-kVA variable frequency up to 2 kHz
- 15-kW turbo alternator
- 100-kW Brayton alternator under development

Space Electrical Power Systems Lab

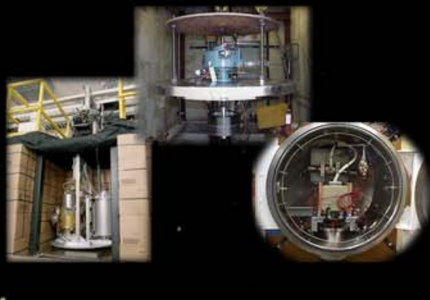
- 1600-sq-ft raised-floor lab environment for space power systems design, integration, and testing
- Integrated with remote test cells for high-energy sources and loads

Telescience Support Center (TSC)

- 5000-sq-ft-area set up for conducting payload operations
- TSC is also a communications and data center capable of handling terabytes of downlinked data

High Bay Clean Room

- 5000 sq ft
- 53-ft-high bay
- Class 100 000 clean room



National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Advanced Life Support Systems

Develop advanced technologies that enable a spacecraft and off-world habitats to meet specific needs to support life in the absence of the Earth's natural life support system. The functions provided by advanced life support systems include appropriate atmosphere composition and pressure; sufficiently pure water for consumption, foods, and hygiene; temperature control of the living environment; foods necessary for nutrition; and collection, processing, and storage of waste to maintain a sanitary environment.

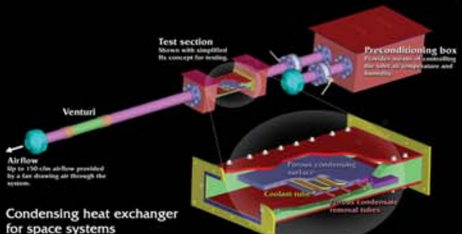
Air revitalization
A system that removes the CO_2, moisture, and other contaminants from the cabin air and replenishes the oxygen consumed by the crew. A nearly closed-loop system that regenerates the required constituents with limited supplies is desirable for long-duration missions.

Water reclamation
A system that collects and processes water from all waste streams and turns it into potable water with minimal supplies to ensure sufficiently pure water for consumption, foods, and hygiene.

A standard, single-blade kitchen mixer in operation with water (left) or with glass beads (right) in microgravity.

Solid waste management
A system that addresses food processing and storage.

Food management system
Addresses food storage through food preservation, packaging, and stowage method to provide food that is safe and appealing for a long-duration mission.



Condensing heat exchanger for space systems

Thermal control
A system that ensures proper temperatures necessary for human habitation and associated equipment.

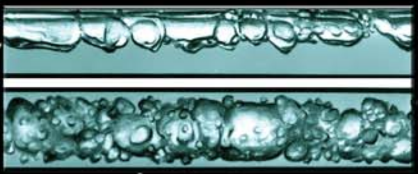
Biomass production
Plants (biomass) can be grown in space to produce food for astronauts and maintain a healthy environment. Plants grow using CO_2 and produce O_2 that replenishes the air supply and also reduces contaminants in the water supply by transpiration (evaporation of water from the leaves) and through microorganisms in their roots.

Multiphase Flow Technology

Multiphase Flow Technology (MFT)
Enables the use of two-phase systems in the areas of human and robotic thermal management, power conversion, and life support in the area of wastewater gathering and processing.

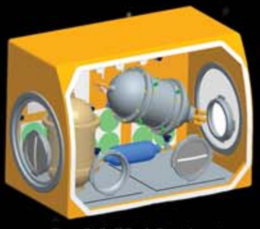
Phase Separation
Advanced life support requires phase separation in atmospheric and water systems and in food processing.

Bubble generation in microgravity



Multiphase flow

Phase Change Heat Exchangers
Two-phase loops are ideally suited for efficient removal of large heat loads since they offer much better heat-load-to-weight ratio than boilers and evaporators used on Earth.



Zero-Boiloff Tank Experiment

Propellant and Liquid Management
In current passive storage systems, venting is used to relieve pressure due to self pressurization resulting in larger tanks. The added mass can make the use of cryogenic propellants and life support fluids prohibitive. Investigates the effectiveness of zero-boiloff (ZBO) strategy as a means for eliminating self pressurization, stratification, and mass loss in space cryogenic storage tanks.

System Stability
Prevents multiphase system instabilities that may occur with the use of phase change systems and processes. Provides verification and validation of closed-loop thermodynamic systems on low-gravity aircraft and the space station.

Constrained Vapor Bubble flight module

Capillary Flows
The capability to acquire, transport, and reject waste heat from life support systems reliably and efficiently with minimum power, mass, and volume is crucial to enabling extended human exploration of space. Verifies and validates wickless heat pipe technologies via experiments and conducts studies of capillary corner flows as a means to provide drainage in low-gravity conditions.

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

Advanced Extravehicular Activity (AEVA) Systems

AEVA Program Goals

Develop advanced space suits, tools, and vehicle interface systems to enable the long-term habitation and exploration of the lunar and Martian surface, as well as support long-duration space journeys required to extend human presence beyond Earth's orbit.

Advanced Communications, Avionics, and Informatics for Extravehicular Activity (EVA) Operations

Develop an integrated communications system to deliver voice, high-quality video, and data on a single communications stream to increase mission productivity and science return

Develop advanced avionics, including electronics, computers, controls, sensors, and displays, to create a smart suit that will provide autonomous control of suit functions to reduce the astronauts' workload and increase mission productivity

Develop advanced Informatics software to operate the space suit, monitor the crew members' health, and manage the data intelligently, in order to increase autonomy of the crew member and efficiency of EVA operations

Advanced Power Systems for EVA Operations

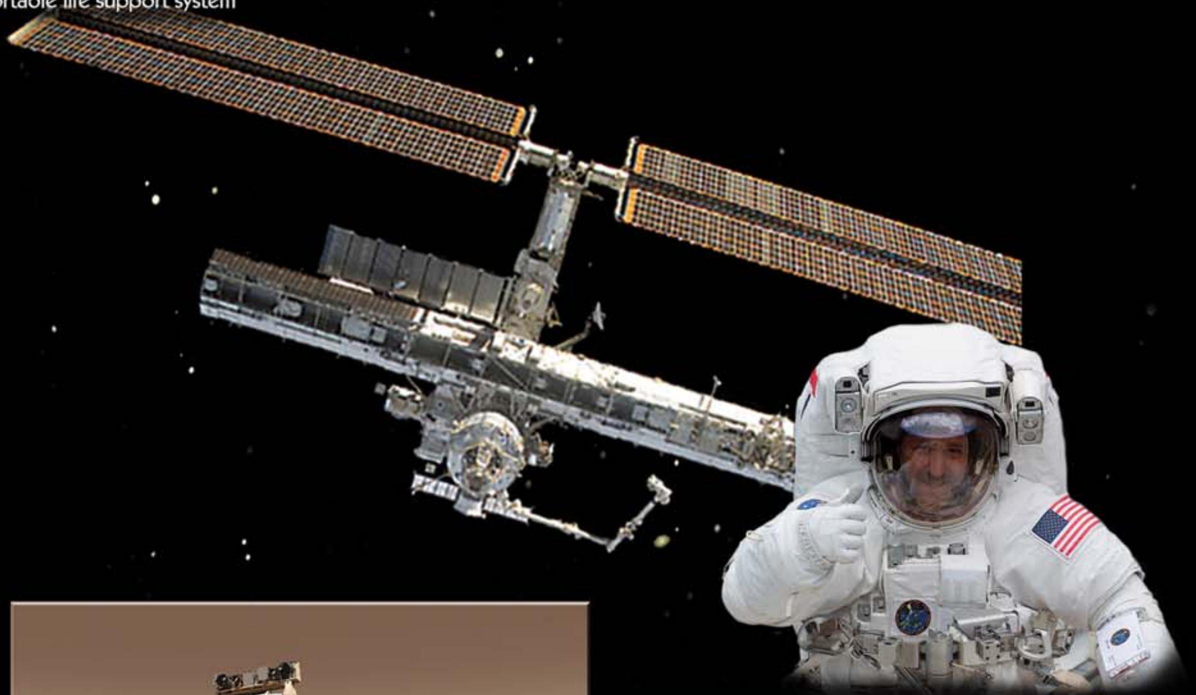
Develop lightweight, high-energy density power storage devices to provide long-life, low-maintenance, modular power solutions to support in-space and surface suits and tools

Dust Characterization and Mitigation Strategies for EVA Surface Operations

Characterize the lunar and Martian dust environment in which space suits must operate and develop testing and simulation techniques to evaluate various mitigation strategies to ensure long-term durability of EVA systems

Advanced Materials for EVA Operations

Develop lightweight, flexible, thermally insulating materials for the suit garment and lightweight structural materials for use in portable life support system



National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

Fire Prevention, Detection, and Suppression

Understanding how fires form and propagate in exploration environments and developing new fire prevention, detection, and suppression technologies for exploration spacecraft and habitats with the ultimate goal of reducing risks associated with spacecraft fires.

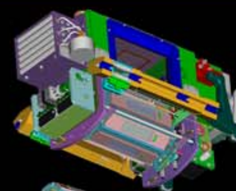
Fire Prevention and Material Flammability

Materials are selected during system design and operation to minimize the probability of fires. The tests to be conducted to assess material flammability are defined in the vehicle specifications.

Products

- *Normal gravity material flammability test to evaluate reduced gravity flammability*
- *Material flammability assessment in candidate atmospheres for exploration transit vehicles and habitats*

Material flammability being evaluated using NASA-STD-6001 Test 1 in 1-g.



FEANICS insert and carousel

CIR

Low-g material flammability will be evaluated in the Flow Enclosure Accommodating Novel Investigations in Combustion of Solids (FEANICS) in the Combustion Integrated Rack (CIR).

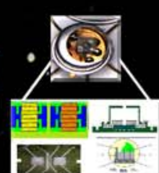
Fire Signatures and Detection

A distributed sensor network tuned to monitor the appropriate fire signatures would provide rapid, location-specific response while minimizing false alarms. Recognizing and locating a prefire event enables simpler mitigation or suppression procedures and decreases the impact to the mission.

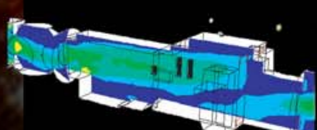
Products

- *Advanced detection system for gaseous and particulate prefire and fire signatures*
- *Verified models of the transport of contaminants, smoke, and combustion gases throughout the habitable volume*

The Smoke Aerosol Measurement Experiment will be conducted in the Microgravity Science Glovebox on ISS to quantify prefire signatures in low gravity and evaluate candidate detection technologies.



Next-generation fire detectors will incorporate MEMS-based technology for detecting chemical species and smoke.



Simulations of smoke and contaminant transport in a spacecraft will aid in the design of detection systems.

Fire Suppression and Response

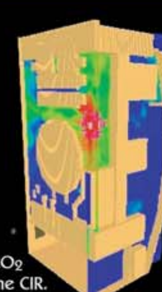
A robust and reliable means to suppress a fire must be available. Data must be available for the rational design of fire suppression systems in low- and partial-gravity environments. Recovery and clean-up after use of a suppressant must be predictable and timely.

Products

- *Design rules for suppressant system including effectiveness of suppressants, required concentrations, and dispersion methods*

The Multiuser Droplet Combustion Apparatus will be used to screen fire suppressant effectiveness in relevant atmospheres in CIR

Spacecraft Fire Safety Facility in the KC-135.



Simulation of CO_2 dispersion in the CIR.

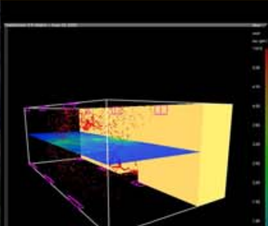
Fire suppression agent effectiveness and dispersion methods will be evaluated through simulation and testing in ground-based microgravity facilities.

Fire Scenarios and Training

Performance-based fire safety methods can be used to quantify and assess the level of protection provided by a fire safety strategy. Methods developed for terrestrial applications will be applied to the unique characteristics of fires in low- and partial-gravity. Simulation tools will be developed to evaluate response protocols and provide realistic crew training modules.

Products

- *Definition and analysis of realistic fire scenarios for exploration spacecraft and habitats*
- *Simulations of fire and fire-response scenarios for system evaluation and crew training*



Simulation of smoke transport in the ISS U.S. Destiny Lab.

Interactive analysis of fire response scenarios using large-scale virtual reality simulations.

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

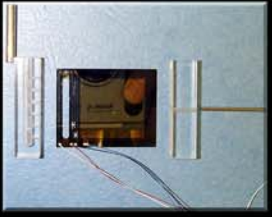
Advanced Environmental Monitoring and Control

Objective

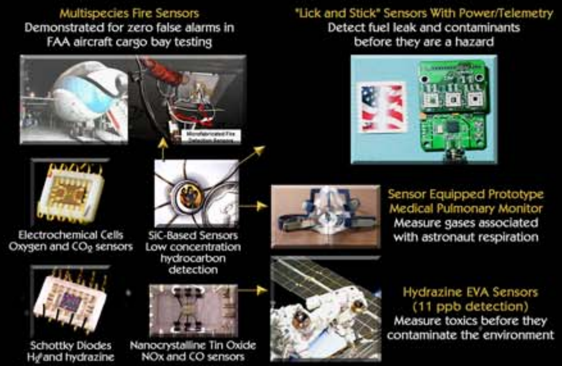
Know your environment: Protect the health of the astronauts and enable a range of exploration missions by developing, demonstrating, and implementing critical detection and control technologies necessary for space habitat environments.

Approach

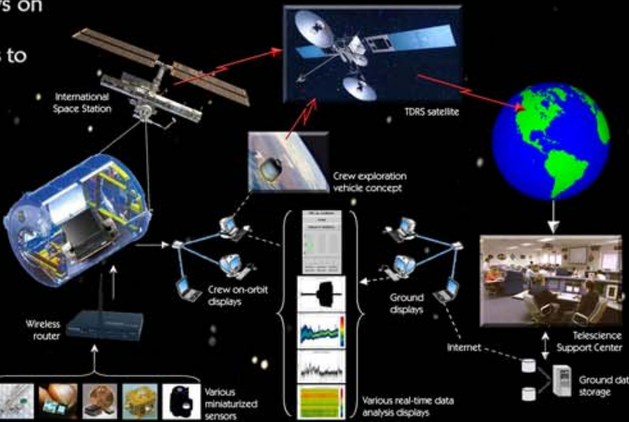
- Develop and integrate both hardware and software into a complete system to intelligently monitor unhealthy conditions onboard spacecraft
- Real-time microsystems monitoring of multiple environmental parameters
  - Aerosol and particulate detection and classification
  - Multispecies chemical and biological detection
  - Vibration and acoustic monitoring
  - Intelligent software systems to process and interpret the data
- Microfabricated aerosol and particulate detectors and classifiers
  - Particulates and aerosols can have significant health effects and must be monitored
  - The astronauts' environment will be exposed to a range of particulates and aerosols (e.g., Moon dust from EVA applications)
  - Demonstrated microtechnology produced by world experts allowing microsystems of significantly reduced size and thus easily integrated
- Micro- and nano-based multispecies chemical and biological detection
  - A range of chemical species need to be determined in closed habitats; this technology provides the tools to know the chemical and biological environment
  - Base microplatform technology and a wide menu of possible microsensor and nanosensor systems which can be tailored for a range of applications
  - Easily applied "lick and stick" technology; demonstrated toxic gas monitoring
- Vibration and acoustic monitoring
  - Noise and vibration effects can lead to cumulative fatigue and asthenia impacting crew cognitive performance and neuropsychological health
  - Microsensor systems to remotely real-time monitor vibration near real time
  - Miniaturized surface mounted microphones deliver acoustics data from fans or other rotating machines in the spacecraft
- Intelligent software systems to process and interpret the data
  - Software system for International Space Station (ISS) use: acquire data, downlink, process, and display on Internet in near real time
  - Artificial intelligence system: quantifies vibration level and identifies responsible systems onboard the ISS in near real time for displays on Internet
  - Modeling contaminant transport in exploration vehicles and habitats to determine sensor placement and response times



Microfabricated aerosol and particulate detectors and classifiers; miniaturization decreases size from traditional systems enabling space vehicle integration



Base platform chemical sensor technology; integration of microsensors and nanosensors into small, rugged sensor suites reliably measuring a range of species



Vibration and acoustic monitoring; complete systems from microsensors and intelligent software to data delivery and display

Applications

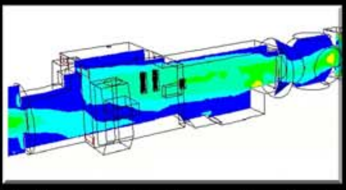
- Multiparameter in situ environment for better understanding of the environment
- Lunar and Mars surface operations and extended human habitation environments
- Long-duration spacecraft and transfer vehicles and spinoffs (e.g., robotic missions)

Benefits

- Full-field knowledge of environment to ensure astronaut health using microsystem technology combined with interpretative software
- We are unique in the range of cross-disciplinary, viable technologies and expertise that we bring to AEMC applications
- Systems can be tailored for application needs

History

- Pioneering research in microparticulate and chemical sensor systems
- 15 years of sensor system development, demonstrations, and application on ISS, shuttle, and Ford Motor Company; multiple awards including R&D 100 Award
- Flown over 20 vibration monitoring missions onboard the space shuttle
- Remote, continuous monitoring on ISS for 4 years using Space Acceleration Measurement System (SAMS) accelerometer system
- Vibration software received R&D 100 Award/NASA second place Software of the Year Award



Modeling of contaminant transport in exploration vehicles to assess sensor placement and response

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Optical Diagnostics, Predictive and Analytical Design Tools, and Biomedical Systems Technology

Mission

Apply advanced optical imaging and microscopy, signal and image processing, sensors and electronic power systems technology, computational and mathematical modeling, fluid physics, and cell culturing capabilities to solve technical challenges in biomedical systems and other fields.

Capabilities

- Analytical and numerical optical system modeling
  — Geometrical and physical optics modeling of propagation, scattering, focused fields, illumination, and detection geometries
- Imaging system design and development
  — Advanced microscopy (Biophotonics Laboratory): Two-photon fluorescence microscopy, three-dimensional near-field microscopy, fluorescence lifetime imaging microscopy, fluorescence correlation spectroscopy, time-lapse videomicroscopy, and live-cell imaging
  — Compact optical probes: dynamic light scattering, laser-doppler flowmetry, autofluoresence, Raman scattering, polarimetry, near infrared spectroscopy, and tissue cappillaroscopy
  — The Compact Microscope Imaging System (CMIS) combining intelligent image processing with remote control capabilities
- Computational and mathematical modeling
  — Soft-tissue mechanics including elastic, viscoelastic, poroelastic, microstructural, and cell dynamics
- Signal and image processing
  — Signal processing and information extraction of electrophysiological signals
  — Image reconstruction from limited data
  — Feature extraction, deconvolution, deblurring, auto-focus algorithms
- Fluid physics
  — Stereo imaging velocimetry used for three-dimensional full-field quantitative and qualitative fluid flow analysis
  — Dynamic light scattering for turbulence characterization
  — Computerized fractal mathematics integrated with the vessel analysis program VESGEN and the intravital microscopic particle imaging velocimetry (micro-PIV) of blood flow
- Sensors and electronic power system
  — Development of invasive and noninvasive sensor measurements of physiological processes and associated power systems
- Cell cultures
  — Biosafety level-1 facility for mammalian cell culture. Other capabilities include immunofluorescence staining, cryostorage, RNA isolation, and gel electrophoresis

Applications

- Microscopy
  — Image system design and development, optical modeling, and image signal processing are performed in the NASA GRC Biophotonics Laboratory
  — CMIS applications include interface detection and tracking, cell labeling and tracking, cell detection and feature extraction, surface identification, and automated patch clamping
- Compact optical probes
  — The optical probe technology is used for noninvasive diagnostics and health monitoring.
- Computational and mathematical modeling
  — Simulation of a bioprosthetic aortic heart valve
- Fluid physics
  — Stereo imaging velocimetry is used for cardiovascular flow verification.
  — Research of the regulation of microvascular responses, including microvascular fluid shifts and angiogenesis/lymphangiogenesis
- Signal and image processing
  — Source reconstruction of electroencephalographic signals during a muscle fatigue task
- Sensors and electronic power systems
  — Research on an in vivo energy conversion system for powering implanted electronic devices

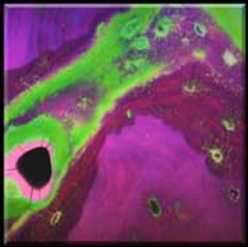
Benefits

- Ground-based and in-flight research is conducted on the effects of the microgravity environment on the human body and on countermeasures to reduce these deleterious effects.
- Contributions are made to the diagnosis and treatment of various diseases and injuries experienced on Earth.
- The developed technology is transferred to the biotechnology industry with beneficial impact.

History

- An interdisciplinary team was formed, consisting of experts with in-depth knowledge of a diverse set of topics, with the ability to contribute to advancing biotechnology for beneficial gain.
- Many of the technological capabilities highlighted are applicable to several technology fields. The individuals responsible for these capabilities have experience in applying the technologies to biomedical problems as well as problems in other fields.

Microscopy



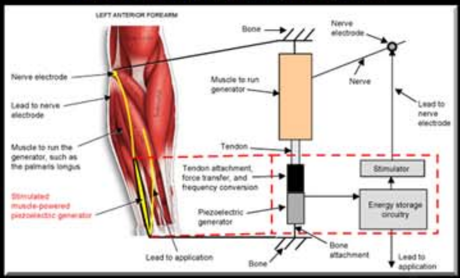
Two-photon image of stained bone tissue. Field of view is 0.2 mm.

Compact Optical Probes

Compact, noninvasive head-mounted ocular health monitoring system

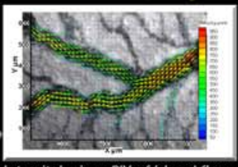
Noninvasive and noncontact detection of ocular and systemic diseases to enable nonsurgical countermeasures

Sensors and Electronic Power Systems



Concept for implanted, stimulated muscle-powered piezoelectric generator

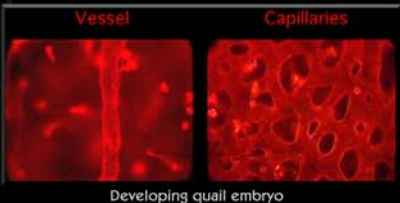
Regulation of Microvascular Responses



Intravital micro-PIV of blood flow in remodeling blood vessels

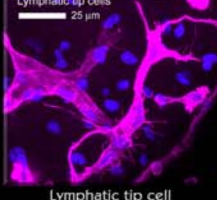
Clinical applications to human retina in early-stage diabetic retinopathy

Vasculature in the Quail CAM



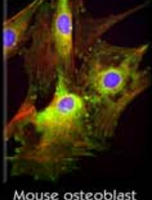
Developing quail embryo

Cell Culture Laboratory



Lymphatic tip cell

Bovine pulmonary artery endothelial cell



Mouse osteoblast (bone-building) cells

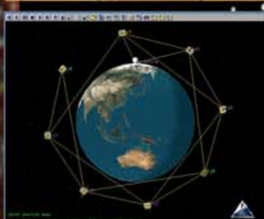
National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Communications, Computing, and Software Engineering

Office of the Chief Information Officer



Exploration Architectures and Testbeds

- Develop intelligent and autonomous computing architectures to permit the interoperation of processors, data storage, communications, and sensors for space exploration
- Provide an integrated, adaptive computational environment for emulating space communication network architectures, intelligent routing and modified communication protocols, and autonomous scheduling for multisatellite sensors
- Space-based distributed computing and storage
  - Autonomous and resilient computational systems
  - Distributed data storage hierarchical configurations
  - Software wrapping technologies for physical and virtual sensors
- Technology evaluation via the In-Space Network Emulation Testbed
  - Modular design enhances reusability, maximizes utilization, and enables "plug-and-play" of different algorithms and protocols
  - Emulate in-space point-to-point communication link, delay and bit error rate, and data traffic from source to destination

Modeling, Simulation, and Visualization

- Advanced data visualization capabilities ranging from ultraresolution displays through fully immersive virtual reality environments that are recognized throughout the aerospace community
- From spacecraft fire safety scenarios to deep-space communication, architectures have been visualized for increased mission understanding

Software Engineering

- Expertise in numerous real-time operating systems for data acquisition, reduction, visualization, and processing for both ground and flight projects
- Developed command and control of experimental science hardware aboard the space station and space shuttle and trained crew for multiple shuttle missions
- Developed mission flight and ground software for microgravity science missions that have flown on the shuttle, sounding rockets, the KC–135 zero-gravity plane, and in drop towers
- Extensive experience conducting mission operations on microgravity science missions
- Necessary skills and practices to build highly reliable space qualified software
- Expertise in digital signal processing, mathematical algorithm development, scientific software, and experimentation approaches
- Software engineering practices independently assessed at capability maturity model (CMM) Level 2 that indicates the ability to reliably develop software for critical applications

Embedded Web Technology

- Leverage the capabilities of the World Wide Web for the command and monitoring of embedded computers via an IP-based network.
- Standard browser software allows user access to embedded computers. All the functions, which will appear to the user, are stored at the embedded system. The user's computer is not customized to a specific embedded system.
- Tempest was the first server of its kind to marry Internet technology and real-time command and control of systems.
  - Awarded the NASA Software of the Year Award in 1998 and the R&D 100 award in 1999.
  - Being used in a variety of industries including medical, military, transportation, space flight, manufacturing, security, fluids processing, etc.
- Biotechnology activities include remote wireless and control and data acquisition of medical devices such as physiological measurement devices with a focus on cardiac arrhythmia monitoring, including T-Wave Alternans. Several prototypes are being tested in clinical trials in a partnership with Case Western Reserve University.

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

Propulsion Integrated System Health Management (ISHM)

Objective

Provide reliable and safe operation of vehicle propulsion systems through state-of-the art, cutting-edge health management systems developed by world leaders

Approach

- All-in-one stop for
  - Nondestructive evaluation
  - Harsh environment sensors and electronics
  - Health management software systems and algorithms
  - Health management applications to propulsion systems

- Nondestructive evaluation:
  Know your system before, during, and after flight
  - Vast array of demonstrated ultrasonic technology
  - Radiographic and tomographic technology
  - Thermal imaging and stress analysis and shearography
  - In situ NDE/structural monitoring: rotor-dynamic systems and piezo patches

- Harsh environment sensors and electronics:
  Smart systems for better operational awareness
  - Physical and chemical sensors are multifunctional and provide multiparameter information including temperature, strain, pressure, heat flux, flow, acceleration, emissions, and leaks
  - High-temperature electronics: world record circuit and package operation
  - High-temperature wireless for reduced weight and improved reliability

- Health management software systems/algorithms:
  Know what you have and what to do with it
  - Sensor selection algorithms: MC–1, RS–83, RS–84 application
  - Data qualification and validation: operational test bed
  - Real-time diagnostics and post-flight diagnostic assessments
  - Integration of NDE into finite element modeling for more accurate models

- Health management applications to propulsion systems:
  We put propulsion ISHM into operation
  - GRC HM algorithms/software, sensors, and NDE technology has been demonstrated and applied in a wide range of applications: Engine test stands/systems, flight demonstrations, and commercial applications

Applications

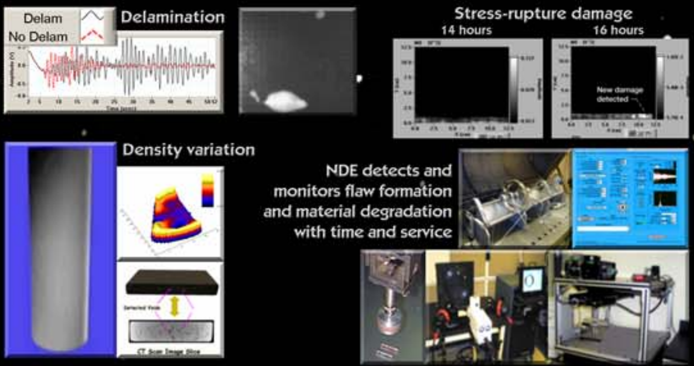
- Propulsion applications throughout the exploration program: launch vehicles, in-space transportation, in situ resource utilization, and lander propulsion systems
- HM technology also applicable to power systems

Benefits

- Reliable, safe, and autonomous propulsion system operation requires ISHM
- Need to know what is happening in the vehicle even in the harshest of environments
- Few groups have applicable technologies. We are unique in the range of viable technologies and expertise that we bring to propulsion ISHM
- Systems can be tailored for application needs
- Parallel control expertise models evaluated/tuned only if true damage state is known

History

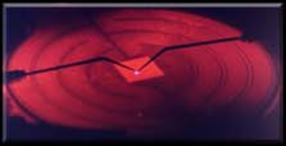
- World-leading group in the development and application of propulsion ISHM algorithms, software, and intelligent harsh environment hardware
- Long list of recognition: multiple R&D 100 awards, recognized leaders, and patented technologies



Nondestructive Evaluation

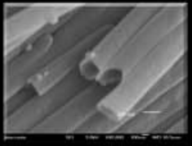
Physical sensors (T, strain, heat flux)

Chemical sensors (leaks and emissions)



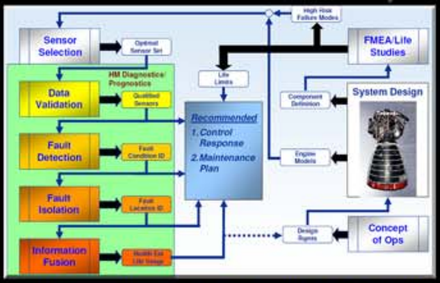
Silicon carbide high-temperature electronics (processing and wireless)

Microelectromechanical systems (high-temperature actuators)



Nanotechnology

Harsh Environment Sensors and Electronics



Health Management Software Systems and Algorithms

Health Management Applications to Propulsion—Applied Sensor Technology

Health Management Applications to Propulsion—Timeline for Algorithm Applications

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

Autonomy and Intelligence

Objective

Develop autonomous and intelligent technologies that are critical to meeting the demands of future air and space transportation and exploration systems.

Autonomous means

Possessing the ability to operate independently, without intervention.

Intelligent means

Possessing the ability to learn, understand, or deal with new situations and to perform functions such as reasoning and optimization based on experience.

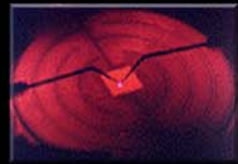
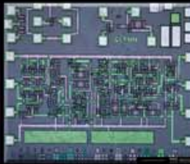
Approach

- Systems that must function for long periods in harsh environments without the possibility of human intervention will require custom hardware and software to ensure robust, reliable operation. This can be accomplished by developing components and algorithms that support the autonomous and intelligent operation of devices and systems. These will in turn enable future air and space transportation and exploration systems.
- The specialized components and algorithms enable vehicle system and subsystem monitoring, data acquisition and processing, intelligent actuation, and communication.
- GRC technology innovations include
  - — Development of miniaturized electronics with harsh environment operation capability, for example, high-temperature, Rad Hard electronics and sensors.
  - — Development of microsensor and nanosensor technology for easy integration to monitor multiple system parameters, for example, "Lick and Stick" technology.
  - — Development of small form factor and low-power communication technology.
  - — Development of advanced robotic locomotion technology for operation on varied surfaces and conditions, demonstrated on miniature mobile robots.
  - — Investigation of advanced control algorithms to enable multi-robotic cooperative inspection and repair.
  - — Development of three-dimensional graphical test bed and simulation tools to facilitate development, testing, and validation of control algorithms.
  - — Development of hardware test bed facility to allow integration, validation, and demonstration of algorithms on robotic hardware.
  - — Development of sensor validation and data fusion algorithms to perform propulsion system diagnostics with high reliability.
  - — Development and integration of algorithms to accommodate propulsion system faults autonomously inflight.

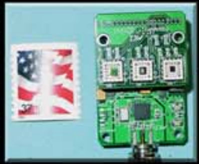
Applications

- Autonomous robotic inspection and repair of air and space transportation and exploration systems. Replace time-consuming manual inspection and repair procedures with high-confidence inspection and repair performed autonomously by cooperative robots.
- Lunar and Martian exploration
- Autonomous propulsion system operation, for manned and unmanned vehicles, with intelligent control system framework including fault detection, isolation, and accommodation (FDIA), and system reconfiguration.

Technology Innovations

High-Temperature Rad Hard Electronics and Sensors



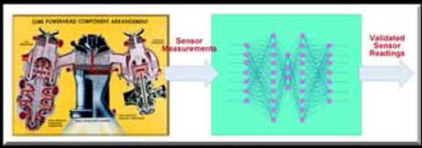
"Lick and Stick" Leak Sensor System

Low Power Communication Demonstration Vehicles

Miniature Mobile Robot

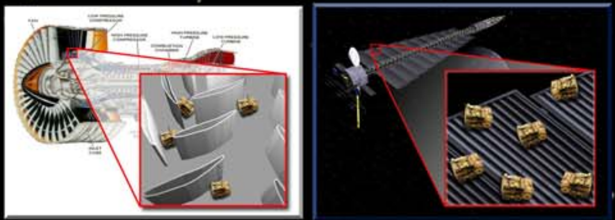
Graphical Test Bed

Hardware Test Bed

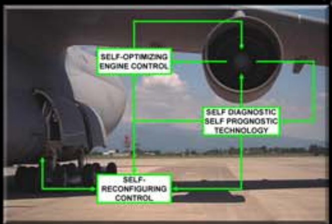


Sensor Validation

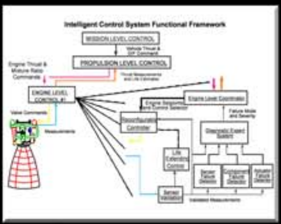
Data Fusion



Autonomous Robotic Inspection and Repair



Autonomous Propulsion System Operation



Intelligent Control System Framework

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Structural Ceramics and Ceramic Composites

Advanced Processing
Composite Design
Coatings and Interphases
Joining and Repair
Property and Life Prediction
Nanotube Structures
Ultra-High Temp Ceramics

Turbine Components
Cooled Structures
TPS/Hot Structures
Combustors
Fuel Injectors
Ducts
Nozzles
Flaps/Seals

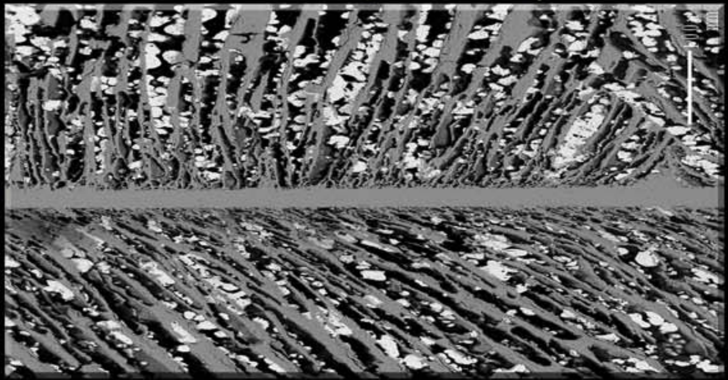
Fundamentals → **Structural Components**

Solid Oxide Fuel Cells

Reducing weight through innovative designs

Bi-Electrode Supported Cell

High Power Densities



Graded Microstructures

Increasing operating temperature and efficiency

Engineering pore structures to enable high fuel utilization

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

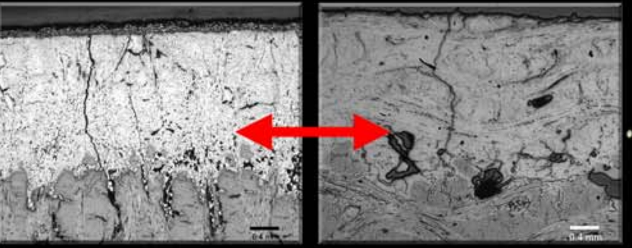
Explore. Discover. Understand.

RMD/Durability and Protective Coatings Branch

High-Temperature Behavior of Materials

Computational Thermodynamics
Identifies possible degradation modes that need to be explored due to adverse reactions with adjoining materials or with the operating environment constituents.

Experimental Kinetics
Determines the kinetic rate of candidate materials degradation modes and their contribution to material failure in the application environment.



Space shuttle reinforced carbon/carbon (RCC) nose cone and wing leading-edge material aging studies.
Left: As-fabricated RCC microstructure; Right: Re-entry mission-simulated RCC microstructure

Experimental Identification and Confirmation of Thermodynamically-Predicted Material Degradation Modes

Free Jet Expansion Sampling and High-Temperature Knudsen Cell Mass Spectroscopy

Unprotected Silicon-Based Structural Ceramics/Composites Show Rapid Recession in High-Temperature Water-Vapor-Containing Combustion Environments

Cyclic Furnace Testing in Water-Vapor-Containing Environments

Durability Testing in Simulated Applications Environments

Rocket Engine Environment Durability Testing of Advanced Structural Materials and Protective Coatings

Cell 22 Rocket Engine

Evaluating Refractory Materials for RCC Leading-Edge Panel Repair Viability

High-Heat-Flux Laser Testing of Materials

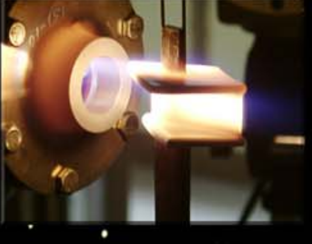
Quick Access Rocket Exhaust (QARE) Rig Low-Cost Testing for Screening Advanced Materials for Rocket Engines

High-Pressure Burner Rig for Material Durability Testing in Simulated Combustion Environments

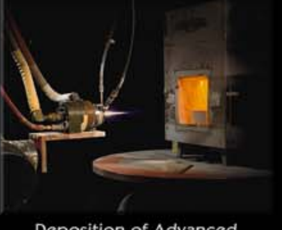
Extending Durability/Life Via Advanced Coatings Development

Selecting the best material for a given propulsion/power application necessitates understanding the critical material property requirements and determining the properties/performance for each candidate material. When no material possesses all of the required properties, the focus becomes optimization of the critical material properties they do have and identification of other approaches to meet all application requirements. Coatings can often provide the protection which allows the coated material to be used with confidence. RMD coating development/application interests are in the following generic types of coatings:

- Thermal barriers
- Oxidation resistance
- Corrosion resistance
- Diffusion barriers
- Erosion and wear resistance
- Chemical compatibility
- Property tailoring



Evaluating Advanced Thermal and Environmental Barrier Coatings on a Silicon Nitride Vane



Deposition of Advanced Barrier Coatings

Oxidation- and Reduction-Resistant Copper- and Nickel-Based Coatings for NASA GRCop-84 Thrust Cell Liners

National Aeronautics and
Space Administration

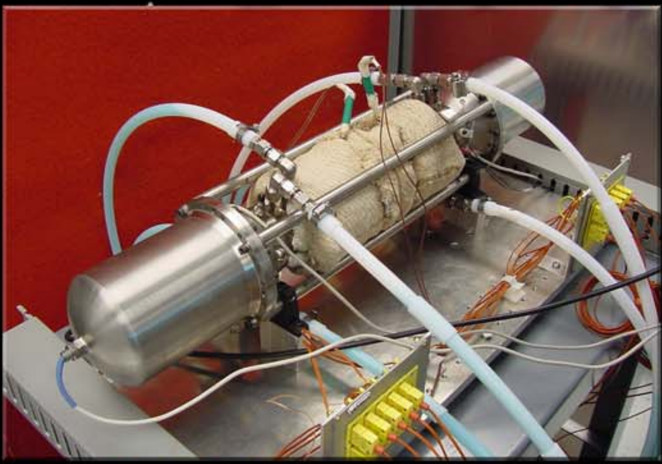
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

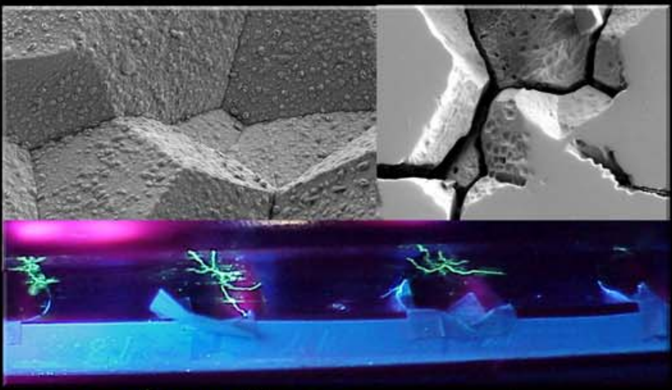
Metallic Materials for Space Propulsion and Power

Materials Applications Engineering

Advanced Copper Alloy GRCop-84 for Rocket Engines
- Highest performance available
- Compatible with multiple fuels

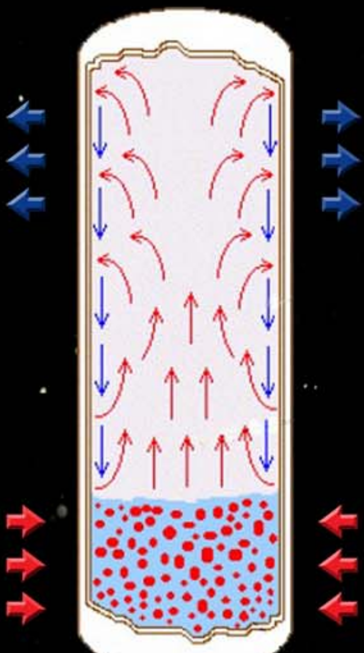


Stirling and Brayton Engine Applications
- Nickel alloys
- Refractory metals



Reaction Control System Thrusters
- Cracking root causes investigation

Materials for Thermal Management



- Heat pipe materials
- Radiator materials

Alloy Durability Testing
- Creep tetsing in air, inert gas, and ultra high vacuum

National Aeronautics and Space Administration

Glenn Research Center

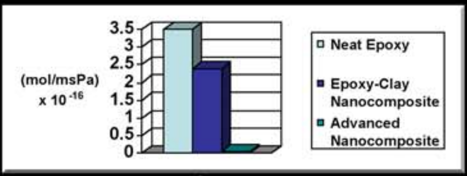
Exploration Systems

Explore. Discover. Understand.

Advanced Polymeric Materials

Objective

Reduce the weight and improve the performance of future exploration mission systems (vehicles, habitats, rovers, and extravehicular activity (EVA) suits)



Approach

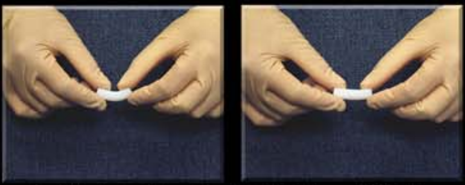
Develop durable, processable, and lightweight materials for structural, power, and propulsion components

- High-temperature polymers and fiber-reinforced composites
- Nanostructured materials
  - Polymer/clay nanocomposites
  - Polymer cross-linked aerogels
  - Carbon nanostructure (graphene platelets and carbon nanotubes) composites
- High-efficiency battery electrolytes and fuel cell membrane materials

Nanocomposites and Aerogels for Advanced Cryotanks

Applications

- Propulsion components
- Vehicle hot structures
- Cryotanks
- EVA suits (insulation and packaging)
- Lithium-polymer batteries
- Proton exchange membrane (PEM) fuel cells
- Pressurized rovers
- Inflatable habitats



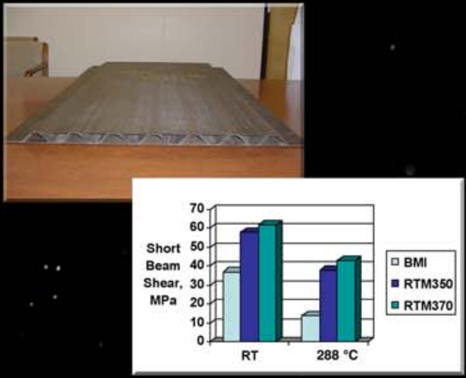
Flexible Aerogel Insulation for EVA Suits and Habitats

Benefits

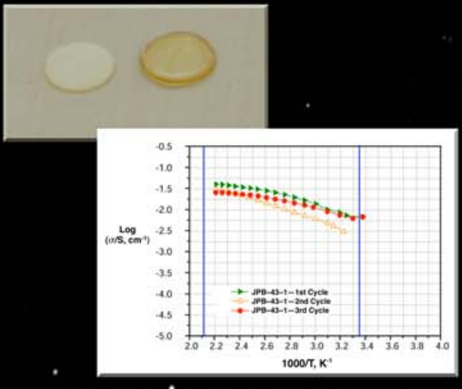
- High-temperature polymers and composites enables 30 percent reduction in component mass
- Low permeability nanocomposites and aerogel insulation will reduce cryotank mass by 20 to 30 percent
- Flexible aerogel insulation and ultralightweight polymeric materials will enable significant reduction in EVA suit and PLSS (Personal Life Support System) mass
- Improved electrolytes will enable operation of lithium polymer batteries at low temperatures and lead to higher specific power
- High-temperature membranes will enable higher power density PEM fuel cells

History

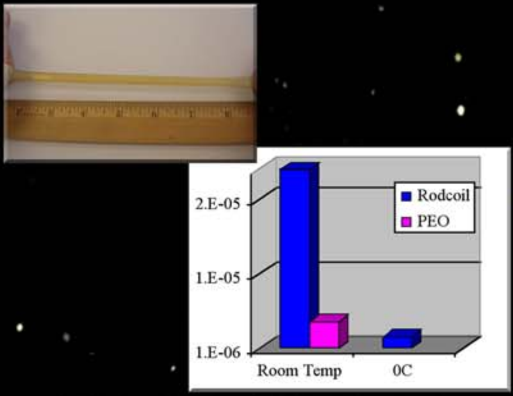
- Polymeric materials have been used extensively in military and commercial aircraft
- Significant improvements have been made in durability, properties, and performance of composites (conventional and nanostructured materials) over the past 5 years that could enable significant reductions in component weight and improvements in durability and efficiency
- Use of lithium polymer batteries in space applications has been limited by poor low-temperature performance of solid polymer electrolyte—recent advances overcome these short fallings
- Conventional PEM fuel cells cannot operate effectively above 80 °C due to poor high-temperature performance of membranes—new membranes can now operate at 200 °C without need for external humidification.



High-Temperature Polymers and Composites



High-Temperature PEM Fuel Cell Membranes



Solid Polymer Electolytes for Lithium-Polymer Batteries

National Aeronautics and
Space Administration

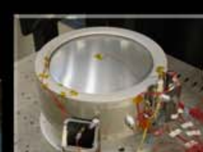
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Electric Propulsion

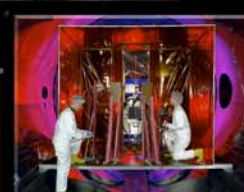
Test Facilities

- Sixteen Major Vacuum Chambers (.02 to 1133 cubic meters) with pumping speeds up to 3,600,000 liter/s air at 1×10^{-5} torr
- Over one dozen assorted-sized bell jars
- Control rooms/machine shop/clean room
- In-house capability to fabricate laboratory and flight hardware



Capabilities

- Ion thruster design, fabrication, and evaluation
- Hall thruster design, fabrication, and evaluation
- Power electronics design, breadboarding, and evaluation
- Experience with experiment package system integration, system qualification, and acceptance testing
- Thermal, stress, vibration analysis, and test
- World-class vacuum facilities and electric propulsion evaluation hardware
  - — Vacuum facilities
  - — Precision thrust stands
  - — EMI measurement apparatus
  - — Plasma diagnostics
  - — High-power, high-voltage laboratory power consoles



Accomplishments

Electrostatic Propulsion

? • Electron Bombardment Ion Engine Invented (1958)
? • SERT I Flight (1964)
? • SERT II Flight (1970)
? • 200-kW, 1.5-m ion engine tested (1965)
? • IR100 Award for Electron Bombardment Ion Thrusters (1970)
? • Developed 5-, 8-, 12-, and 30-cm engine with Hughes (1970–1982)
? • 10,000 hour test of 30-cm ion engine (1975)
? • Ground tests of two-engine SEPS stage module (1979)
? • IAPS developed to flight status (1980)
? • Patents for dished grids, ring-cusp engine, xenon hollow cathodes (1973,1981, and 2000)
? • Russian-developed Hall Effect Thruster technology evaluated at GRC (1991–2003)
? • GRC supplied hollow cathodes used for ISS charge control (1994)
? • Boeing XIPS–13 and XIPS–25 use GRC-developed technology (1997)
? • 600-W Hall Effect Thruster evaluated on NRL spacecraft (1997)
? • GRC responsible for development of DS1 ion engines and power processors (1997)
? • R&D 100 Award for the Ring Cusp Ion Thruster (2001)
? • 16,265 hours of in-space operation of the DS1 ion engine (2002)
? • NASA Invention of the Year for ISS hollow cathode (2002)
? • More than 28,000 hours of operation of the DS1 flight spare ion engine at JPL (2003)
? • GRC chosen to lead development of 5-kW-class NEXT ion engine (2002)
? • GRC chosen to develop 25-kW-class HiPEP ion engine (2002)
? • Demonstration test of a 100-kW-Hall Effect Thruster (2003)

Electrothermal Propulsion

? • Resistojets developed for stationkeeping, attitude control, and MORL propulsion (1960–1972)
? • Developed with AVCO and Giannini 1- and 30-kW arcjets (1963)
? • GRC resistojet technology applied to hydrazine thrusters for Comsats (1976)
? • Transferred 1-kW-class arcjet technology to industry for Comsat propulsion (1987)
? • Waste gas resistojet developed by Rocketdyne/Technion for space station (1988)
? • 10,000 hour test of an EM resistojet for space station applications (1990)

Electromagnetic Propulsion

? • Early performance validation tests of high-I_{sp} MPD thrusters (1964)
? • GRC contracts with AVCO, EOS, and Giannini Scientific for MPD thruster development (1964–1969)
? • First demonstration of facility pressure effects on MPD thruster performance (1969)
? • Radiation-cooled, 30-kW MPD thruster tested for 500 hours by McDonnell-Douglas via GRC contract (1969)
? • Thrust stand developed for 100-kW-class MPD thrusters (1989)
? • Steady-state hydrogen MPD thruster tested at an I_{sp} of 3700 s and thrust efficiency of 20 percent (1993)
? • PPT attitude control demonstrated on EO1 (2002)

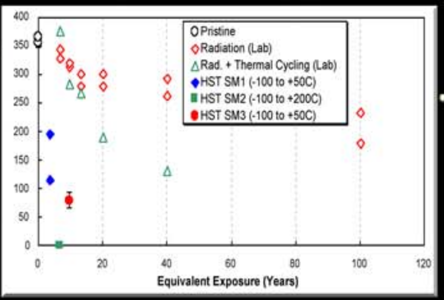
National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Radiation Durability Evaluation

Electron, proton, and ultraviolet (UV) radiation durability
- Highly material dependent
- Can be flux dependent (FEP)
- May require laminate configurations
- Requires flux and temperature calibration
- Can be performed in ground facilities with appropriate calibration



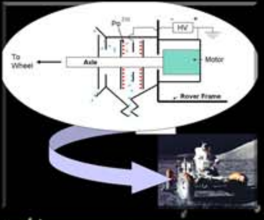
Radiation testing of FEP for Hubble Space Telescope

UV and vacuum ultraviolet (VUV) exposure facility

Mitigation of Lunar Dust

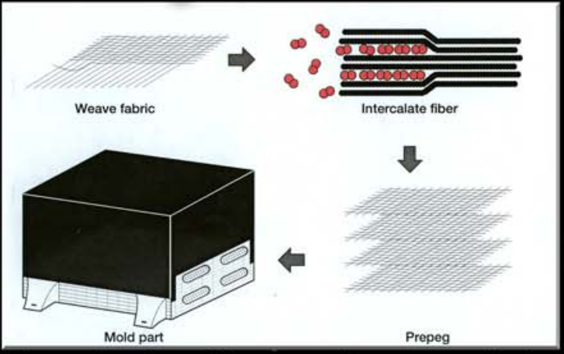
Lunar dust causes
- Contamination (optics and photovoltaic (PV) arrays)
- Degrades radiator performance
- Abrasion and scratching
- Clogs mechanisms
- Compromises seals
- Irritation

Innovative solutions
- Electrostatic discharge of dust
- Photo-discharging of surfaces
- Weakly conducting coatings
- Regolith metallization
- Ultra-smooth coatings
- Elastomer vitirfication
- Work function matching coatings



Lunar Dust Adhesion Facility
- High vacuum
- 100 → 400 K
- Solar UV
- Realistic lunar simulant
- In situ properties measurement

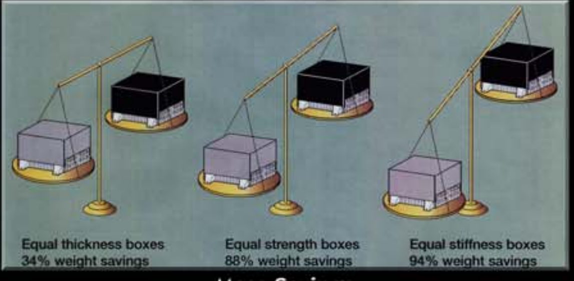
Lightweight Electromagnetic Interference and Radiation Shielding



Intercalated graphite composites use standard laminar fabrication techniques

Property	6061 Al alloy		P-100/epoxy	P-100+Br/epoxy
Electrical resistivity	3.5	μΩ-cm	570 x Al	140 x Al
Tensile strength	0.52	GPa	1.6 x Al	1.6 x Al
Young's modulus	71	GPa	6 x Al	6 x Al
CTE	23	ppm/K	–1.6 ppm/K	–1.6 ppm/K
Thermal conductivity	24.7	W/m-K	10 x Al	10 x Al
Thermal absorbance (1000 nm)	0.02		0.91	0.91
Density	2.71	g/cm^3	61% Al	66% Al

Properties Comparison



Mass Savings


National Aeronautics and Space Administration
Glenn Research Center
Exploration Systems
Explore. Discover. Understand.
NASA
Power Management and Distribution (PMAD)
PMAD is the "glue" that binds the power system together!
PMAD
Power System Control
Sources
Loads
Solar Arrays
Source Regulator
Load Converters
Electric Propulsion
Brayton Rotating Unit
Communications
Power Distribution
Stirling Radioisotope
Charge/ Discharge Regulator
Instruments
Load Leveling
Fuel Cells
Actuators
Batteries
Flywheel Energy Storage
Energy Storage

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

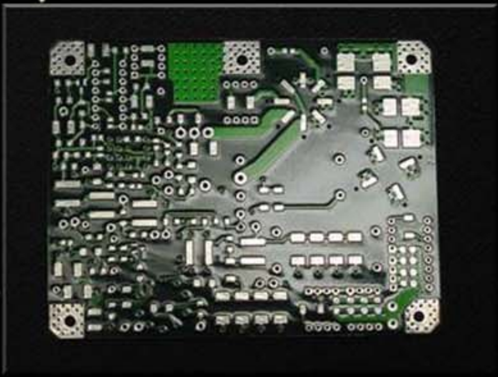
Explore. Discover. Understand.

Thermal Management Technology

Advanced Thermal Management for Aerospace Electronics

- High thermal conductivity gives excellent heat dissipation
- Expansion mismatch reduction between board and chips virtually eliminates thermally induced chip stress
- Enables denser chip population onboard to save overall mass and volume

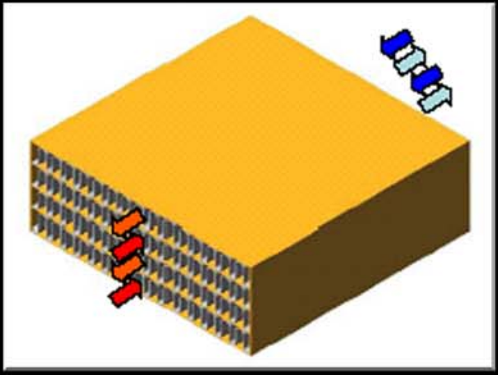
STABLCOR™ Advanced Circuit Card

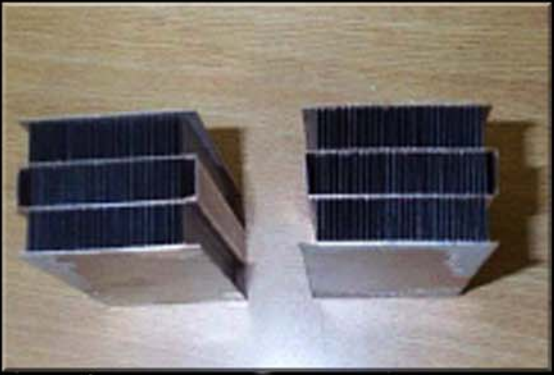


Brayton Carbon-Carbon Heat Exchangers

- Advanced carbon-carbon heat exchanger provides 30 to 70 percent mass savings for equivalent metallic performance (Phase II SBIR with Allcomp, Inc.)
- Advanced analytical studies—In-house and grant with Pennsylvania State University Applied Research Laboratory

Advanced Carbon-Carbon Recuperator

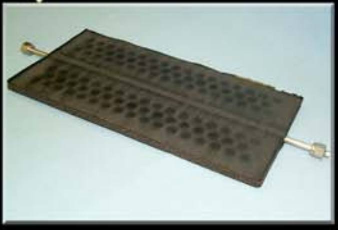




Brayton Power Conversion Heat Rejection

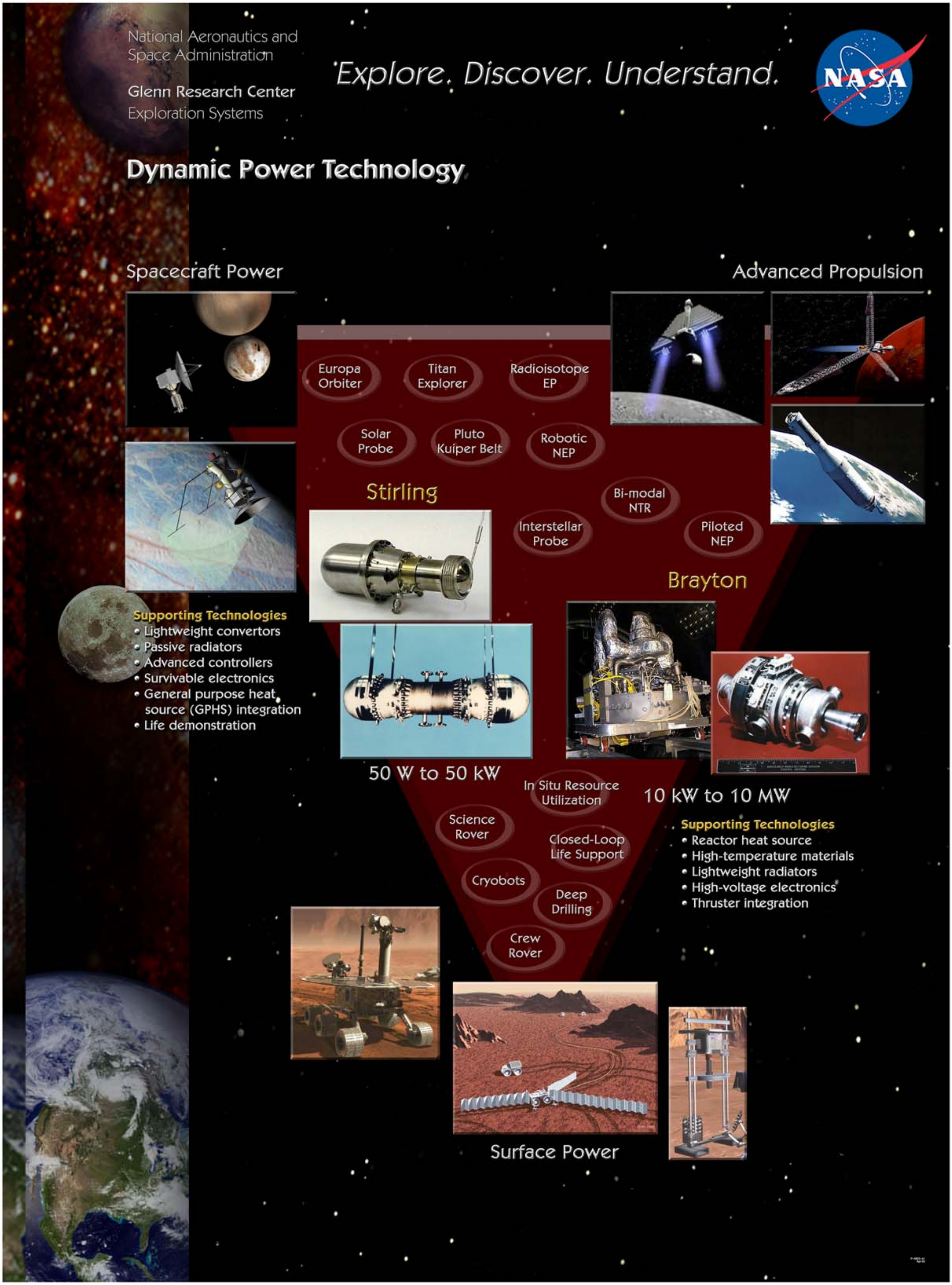
- Functional description
  - — Brayton power conversion waste heat removal and rejection to space
- Physical description
  - — Lightweight radiator panels ($A\mu T^4$)
  - — Micrometeoroid protection
  - — Deployment mechanisms
  - — High-emissivity coatings
  - — Carbon composite materials and aluminum
  - — Key performance metric: areal density (kg/m^2)

Annealed Pyrolytic Graphite Space Radiator



Carbon-Carbon Heat Pipe Radiator

Expertise: GRC, AMT, Swales, Lockheed Martin, Dynatherm, Thermacore, Rocketdyne, Air Force Research Laboratory, K-Technologies, Pennsylvania State Applied Research Laboratory, University of Cincinnati, and others.


National Aeronautics and Space Administration
Glenn Research Center
Exploration Systems
Explore. Discover. Understand.
NASA
Dynamic Power Technology
Spacecraft Power
Advanced Propulsion
Europa Orbiter
Titan Explorer
Radioisotope EP
Solar Probe
Pluto Kuiper Belt
Robotic NEP
Stirling
Bi-modal NTR
Interstellar Probe
Piloted NEP
Brayton
Supporting Technologies
• Lightweight convertors
• Passive radiators
• Advanced controllers
• Survivable electronics
• General purpose heat source (GPHS) integration
• Life demonstration
50 W to 50 kW
In Situ Resource Utilization
10 kW to 10 MW
Science Rover
Closed-Loop Life Support
Supporting Technologies
• Reactor heat source
• High-temperature materials
• Lightweight radiators
• High-voltage electronics
• Thruster integration
Cryobots
Deep Drilling
Crew Rover
Surface Power

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

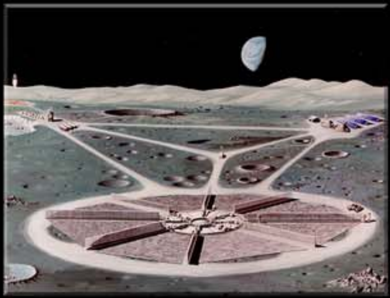
Explore. Discover. Understand.

Prometheus Nuclear Propulsion and Power Conversion Technology Development for Robotic and Human Exploration

Nuclear Electric Propulsion

The high-specific impulse of electric propulsion means going farther with less propellant mass. Advanced electric propulsion technologies can stretch this advantage farther through increased thruster lifetimes, alternative propellant use, and high-power-density thruster technology development. GRC capabilities include

- Ion and Hall long-life and high-power thruster development
- Magnetoplasmadynamic or other high-power electric propulsion concept thruster technology development
- Thruster power processor technology development
- Integrated electric propulsion system technology maturation
- Electric propulsion mission and systems analysis



Dynamic Power Conversion and Related Technologies

Brayton, Stirling, and potassium Rankine cycles offer high-conversion efficiencies that deliver more electric power and less waste heat to radiate. These technologies are equally applicable to space transportation and surface systems. Advances in dynamic conversion technologies offer increased lifetime and reliability, and reduced system mass. GRC capabilities include

- Converter system technology development and testing
- Heat rejection system technology development, including heat exchangers and heat pipes
- Power management and distribution technology development
- High-temperature materials technology development

Mission Analysis and Requirements Definition

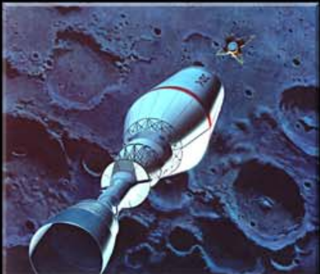
Making sense out of the advantages of multiple technologies for space propulsion and power generation requires expertise and advanced capabilities in mission and systems analysis. GRC capabilities include

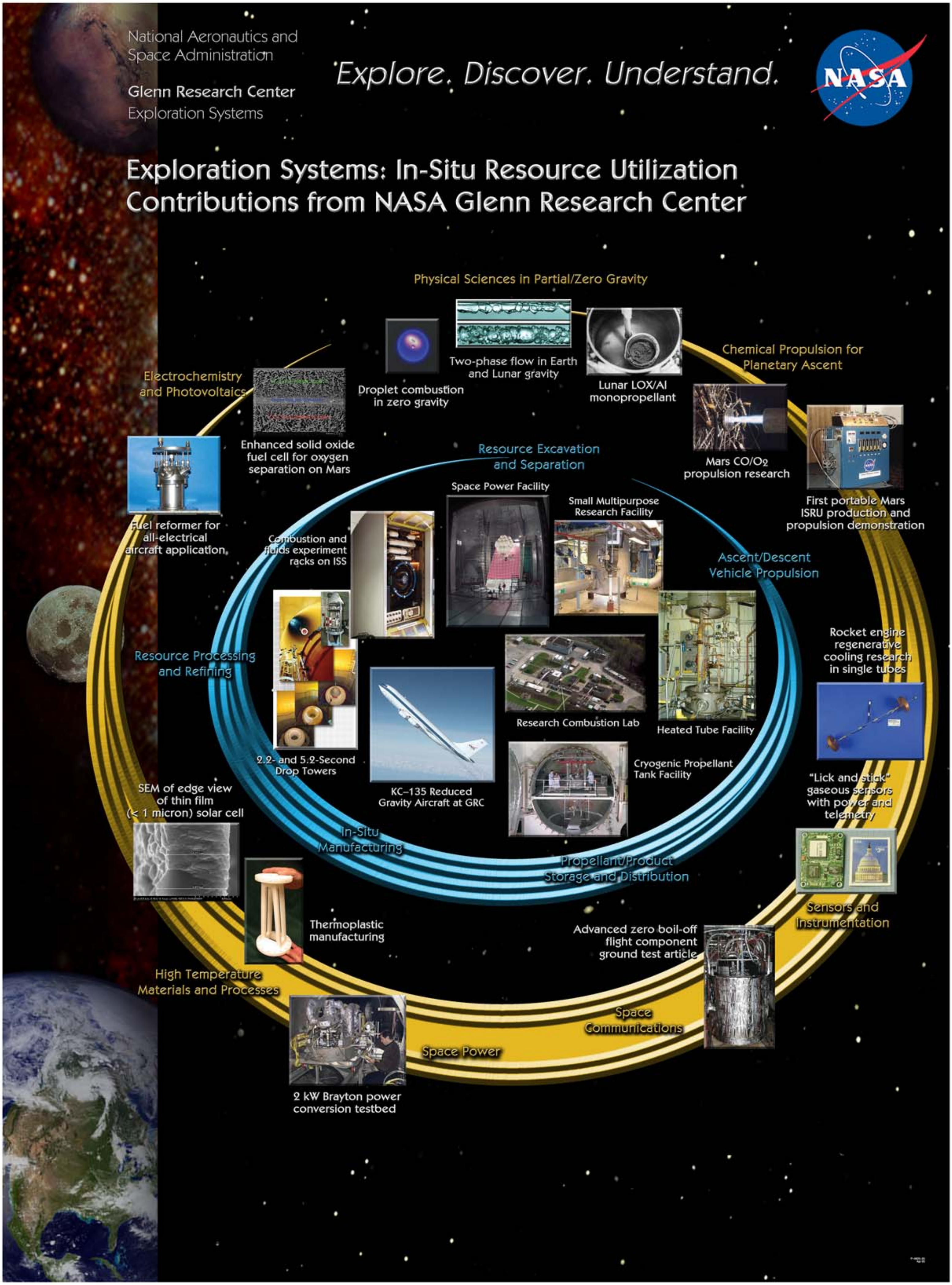
- Low-thrust, high-thrust, and hybrid systems mission design and trajectory analysis
- Technology trades and benefits assessments for propulsion and power systems, including, in many cases, systems costs
- System concept definition and mission architecture development and analysis

Nuclear Thermal Propulsion (NTP)

The combination of high thrust and specific impulse (twice that of chemical rockets) makes NTP hard to beat for short transit time cargo and crewed missions to the Moon, Mars, and elsewhere. GRC capabilities include

- High-thrust trajectory and mission design and analysis
- Engine and vehicle conceptual design and systems analysis
- Cryogenic propellant systems technology application
- Power conversion systems integration for bimodal operation
  of NTP in propulsion and electrical power modes
- Propulsion-related materials and control technologies




National Aeronautics and
Space Administration
Glenn Research Center
Exploration Systems
Explore. Discover. Understand.
NASA
Exploration Systems: In-Situ Resource Utilization
Contributions from NASA Glenn Research Center
Physical Sciences in Partial/Zero Gravity
Droplet combustion in zero gravity
Two-phase flow in Earth and Lunar gravity
Lunar LOX/Al monopropellant
Chemical Propulsion for Planetary Ascent
Mars CO/O2 propulsion research
First portable Mars ISRU production and propulsion demonstration
Electrochemistry and Photovoltaics
Enhanced solid oxide fuel cell for oxygen separation on Mars
Fuel reformer for all-electrical aircraft application
Resource Excavation and Separation
Space Power Facility
Small Multipurpose Research Facility
Combustion and fluids experiment racks on ISS
Ascent/Descent Vehicle Propulsion
Resource Processing and Refining
Research Combustion Lab
Heated Tube Facility
Rocket engine regenerative cooling research in single tubes
2.2- and 5.2-Second Drop Towers
KC-135 Reduced Gravity Aircraft at GRC
Cryogenic Propellant Tank Facility
"Lick and stick" gaseous sensors with power and telemetry
SEM of edge view of thin film (< 1 micron) solar cell
In-Situ Manufacturing
Propellant/Product Storage and Distribution
Sensors and Instrumentation
Thermoplastic manufacturing
Advanced zero boil-off flight component ground test article
High Temperature Materials and Processes
Space Communications
Space Power
2 kW Brayton power conversion testbed

National Aeronautics and Space Administration

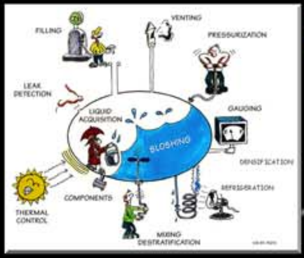
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Cryogenic Fluid Management in Low Gravity

Cryogenic Propellants

- Current areas of cryogenic research
  - Pressure and thermal control
  - Liquid quantity gauging
  - Fluid transfer
  - Liquid acquisition
- Other recent cryogenic research includes propellant densification, tank pressurization, and propellant feed system chilldown
- Benefits
  - Low-gravity cryogenic propellant management is enabling technology for the Nation's goals of future exploration
  - High I_{sp} propellant combinations
  - Environmentally friendly

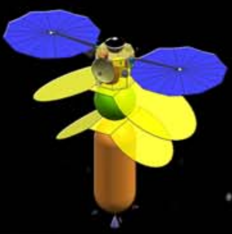


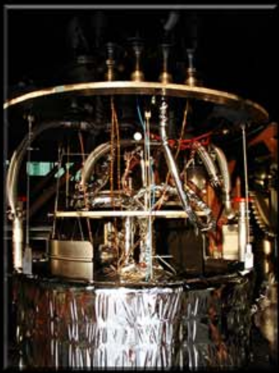
Cryogenic Propellants Challenges

Propellant Tank Pressure and Thermal Control

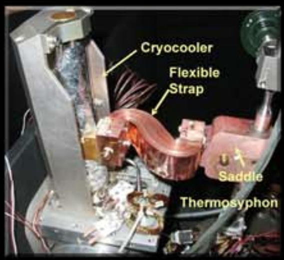
- Objective: Develop pressure and thermal control designs to reduce propellant tank heating and minimize its storage mass
- Analytical Model
  - Cryogenic analysis tool (CAT) modeling
    - Zero-boiloff (ZBO) and low-boiloff modeling using a combination of advanced technology active control (cryocoolers), passive control (insulation), and/or preferential vehicle orientation
      - All ZBO and passive components are modeled
      - Multilayer insulation (MLI), boiloff, radiator, and power trades are conducted to minimize storage mass
    - Three-dimensional configuration designs are evaluated using TSS software radiation models
      - Configurations iterated upon to achieve lowest possible heating rates
- Experimental Model Validation
  - Simulated in-space conditions
  - Flight-type cryocooler, radiator, heat pipe, fin, and TVS
  - LH_2 and LN_2 cryogenic pressure/thermal control testing
- Benefits
  - Reduce mass and cost by studying three-dimensional models and optimizations
  - Validated models through testing

Cryogenic Storage Configuration Selected from Three-Dimensional Model of Sample Return Mission



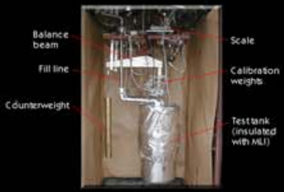


Validation Test Hardware



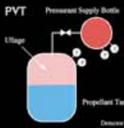
Liquid Quantity Gauging

- Objective: Measure cryogenic liquid quantity in low gravity without resorting to propellant settling
- Approach
  - Examine multiple concepts in parallel
    - Compression gauge
    - Pressure-volume-temperature (PVT)
    - Optical gauge
    - Other new concepts
  - Perform ground tests to demonstrate proof-of-concept and advance technology level and validate gauging accuracy claims
  - Validate concepts in low gravity
- Benefits
  - Monitors propellant consumption during on-orbit maneuvers
  - Vehicle health monitoring between maneuvers (leak detection)
  - Enables lower propellant margins, leading to greater payload-to-orbit capability

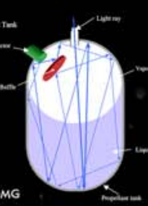


Laboratory-grade scale coupled with a counterweighted LH_2 tank provides benchmark measurement for gauging tests

PVT



CMG



OMG

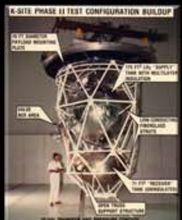
Propellant Transfer

- Objective: Demonstrate fluid transfer by systematically developing technology for umbillicals, tank chilldown, and fluid fill with minimum product loss
- Techniques for single-phase transfer with storables that use membranes to separate liquid/vapor phase not directly applicable to cryogens
- Tank fill techniques experimentally investigated
  - No vent fill—Uses evaporative cooling and subcooling to chill cryogenic tank and transfer fluid without venting
  - Rapid chill and fill—Uses evaporative cooling and subcooling to rapidly chill and fill a cryogenic tank with minimum venting
  - Models validated with ground-based test data
- Drop tower and limited flight experiments such as Vented Tank Resupply Experiment (VTRE) with referee fluids
- Benefits
  - Enables on-orbit cryogenic propellant transfer

Shuttle Transfer Experiment

Vented Tank Resupply Experiment (VTRE)

Transfer Test Hardware



No vent fill transfer test hardware

Rapid chill and fill test tank

Liquid Acquisition Device Test Hardware

View of screen through window during cryogenic screen component tests

Screen channel used for outflow testing

Screen channel and visualization tube installed in cryogenic test fixture

Liquid Acquisition Devices (LADs)

- Objective: Acquire single-phase cryogenic propellants in low gravity for propulsion and fluid transfer activities
- LAD cryogenic data limited to bench testing with screen samples—no flight experience exists
- Approach
  - Develop a design database for cryogenic LADs that will aid a designer in choosing the correct screen and channel geometry
- Benefits
  - Cryogenic LAD development enables the use of high-performance, nontoxic propellants
  - Functionally simple devices
  - Efficient LAD design can lead to low propellant tank residuals

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Thermal Management and Turbine Technology

Thermal management experience in
- Analysis tools
- Complex flows
- Computational and experimental techniques

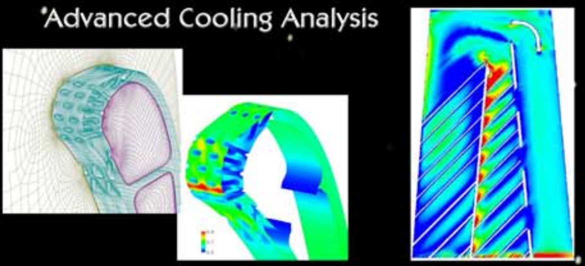
Expertise in developing and applying:
- High-fidelity models
- Highly complex models

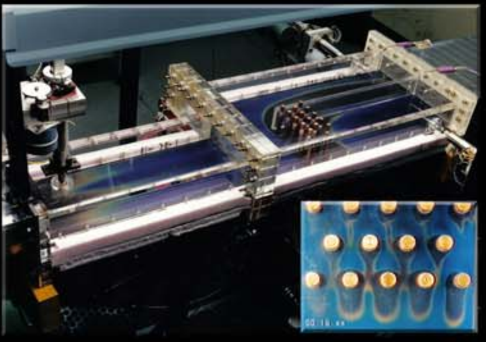
Heat transfer and fluids measurement tools:
- Particle imaging velocimetry
- Laser Doppler velocimetry
- Infrared
- Liquid crystals
- Flow visualization
- Hot-wire anemometry

Experience in advanced cooling schemes:
- Design validation testing and analysis
- Radiative
- Conductive
- Convective
- Conjugate systems
- Heat exchangers
- Ducts and nozzles
- Aircraft icing

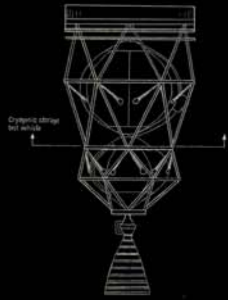
Turbomachinery analysis and design:
- Space-related applications
- Air-breathing applications
  - Aircraft engines
  - Ground power applications

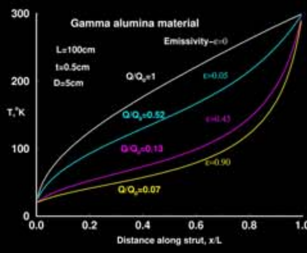
Advanced Cooling Analysis



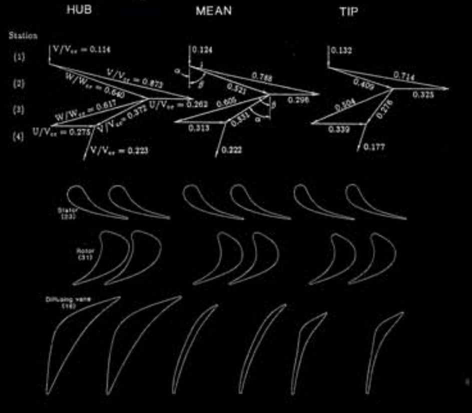


Radiation/Conduction Analysis
Strut Heat Transfer

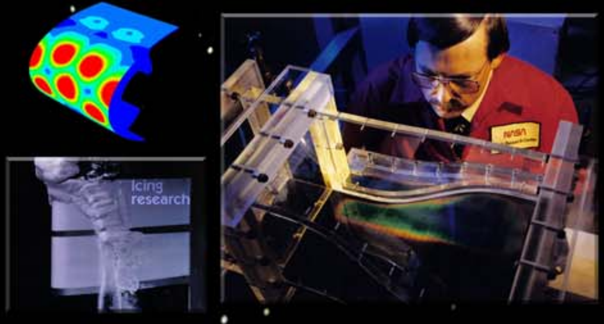




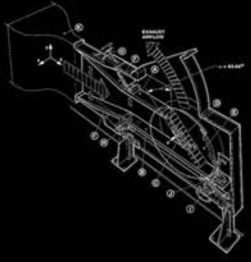
Single Stage Space Shuttle Main Engine (SSME) Turbine Concept

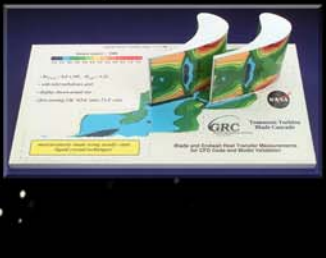


Design Validation



Transonic Turbine Blade Cascade





We can apply the tremendous technological advances of turbomachinery for air-breathing systems to improve the performance and efficiency of turbomachinery for space-related applications.

National Aeronautics and Space Administration

Glenn Research Center

Exploration Systems

Explore. Discover. Understand.

Turbomachinery Design and Analysis Codes

The Compressor Branch at NASA Glenn Research Center has developed several Computational Fluid Dynamics (CFD) codes for design and analysis of pumps, compressors, and turbines.

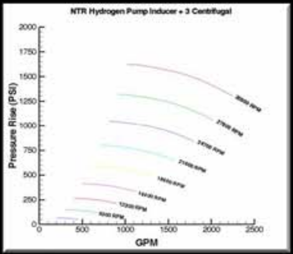
PUMPA—Meanline Analysis and Design

Applications

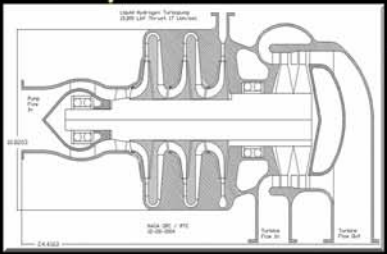
? • Design of axial and centrifugal pumps
? • Estimate off-design performance
? • Single stage and multistage
? • Diffuser and volute design

Details

? • One-dimensional meanline analysis
? • Cavitation model
? • Fluid properties for air, water, LOx, LH_2, and LN_2



Predicted Performance Map for LH_2 Turbopump



Nuclear Thermal Rocket LH_2 Turbopump

H3D—Meanline Analysis and Design

Applications

? • Axial compressors and turbines
? • Pump stages
? • Propellers
? • Incompressible to transonic flows

Details

? • Pressure-based finite-difference solver
? • Steady and unsteady RANS with two-equation turbulence model
? • Unsteady LES mode available
? • Cavitation model

Grid for RLV Pump Stage

Pressures in RLV Pump Stage

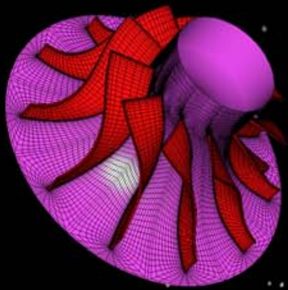
Swift—Three-Dimensional Analysis

Applications

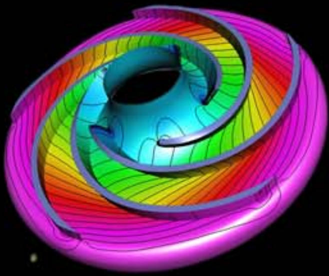
? • Axial compressors and turbines
? • Isolated blade rows or multistage machines
? • Centrifugal impellers and radial turbines without splitters
? • Pumps

Details

? • Grid generation with TCGRID grid code
? • Explicit finite-difference formulation
? • Algebraic and two-equation turbulence models
? • Preconditioning for low-speed flows
? • Available from NASA GRC software repository, https://technology.grc.nasa.gov/software



Grid for a Radial Turbine



Pressures in a High-Head Rise Pump

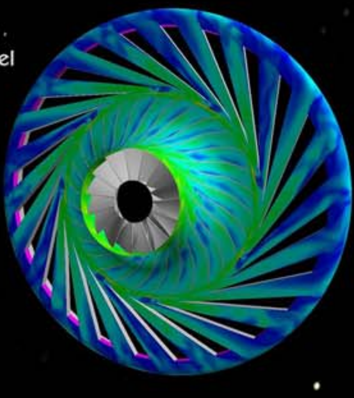
MSUTURBO—Three-Dimensional Unsteady Multistage Analysis

Applications

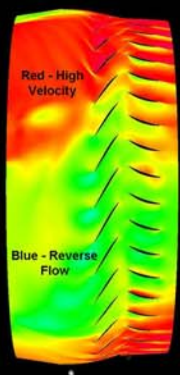
? • Axial and centrifugal compressors and turbines
? • Full three-dimensional unsteady analysis of multistage machines

Details

? • GUMBO preprocessor
? • Implicit finite-volume scheme
? • Advanced two-equation turbulence model designed specifically for turbomachinery
? • Fully parallelized
? • Code available by written request to NASA GRC Compressor Branch



CC3 Centrifugal Compressor and Wedge Diffuser



Axial Velocity in Rotor 35 Without Casing Injection

Axial Velocity in Rotor 35 With Casing Injection

National Aeronautics and
Space Administration

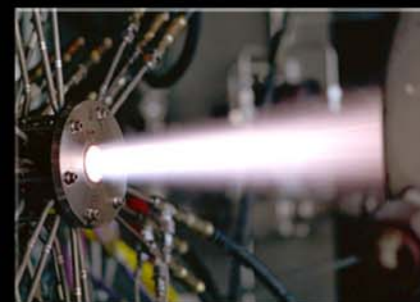
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

Chemical Propulsion

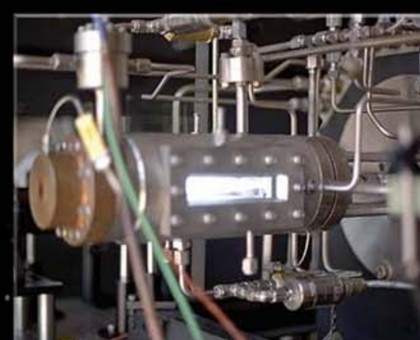
25-lbf-class gaseous hydrogen, gaseous oxygen, regenerative-cooled thruster. Performance tests with 30 to 1 area ratio nozzle in altitude test facility.

Heated Tube Facility



O_2/RP-1/aluminum combustion aerogel and nanoparticulate metals can gel the fuel, making it denser, more energetic, and safer.

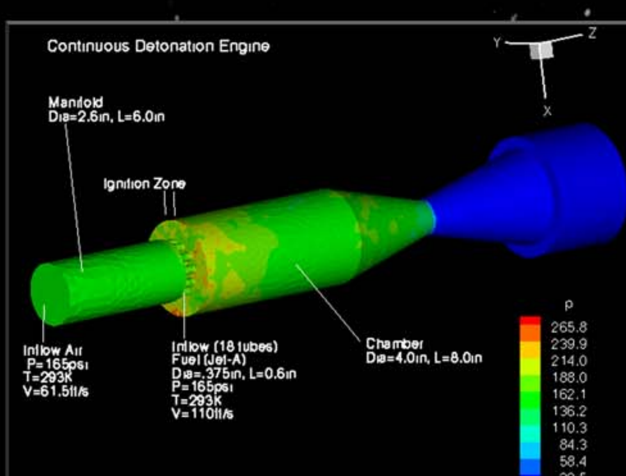
5-lbf-class rhenium thruster life test in altitude test facility. Thruster operated at 4000 °F with radiation cooling for 6 hours on gaseous hydrogen and gaseous oxygen.

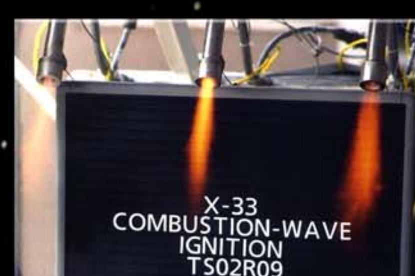


Cell 32 Windowed Combustor Rig

Three-Dimensional, Unsteady Computation for Continuous Detonation Engine

Tuned injection elements/manifold that create an acoustic instability that transitions to a detonation plus higher frequency of operation: valveless heat transfer, off-design operation.





X–33 Combustion-Wave Ignition

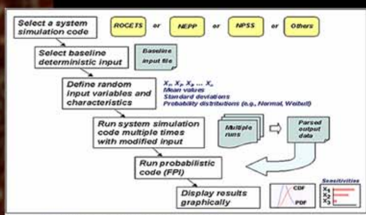
GOx/Methane Combustion-Wave Ignition

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

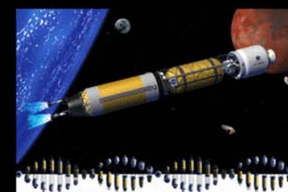
Explore. Discover. Understand.

Advanced Systems Oriented Propulsion Analysis Capabilities Built Upon a Solid Foundation of Experimental/Analysis Experience



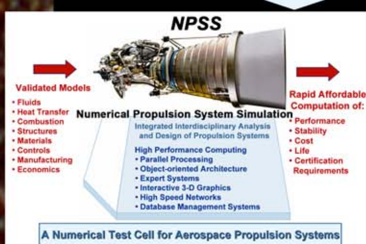
Overall SUA approach to performing probabilistic analyses

Uncertainty Analysis

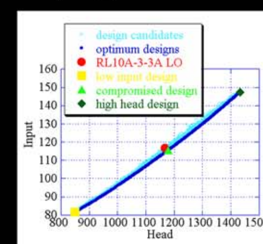


Optimization

System Simulation



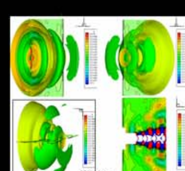
Optimization Using Multiobjective Evolutionary Algorithms (Example: RL–10 Turbopump)

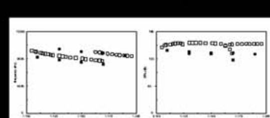


	Original	Low input	Compromise	High head
Head	1167.1	849.1	1179.6	1433.4
Input	116.6	81.6	115.5	147.43

Conservation Element Solution Element (CE/SE) Method for Unsteady Flows

- Aerospace Corporation used method to analyze and explain failure in Titan IV solid rocket motor nozzle
  - Actuator failure due to flow transients at engine startup
- Results compare exceptionally well with several jet noise experiments
  - Experimental results by Nozzle Branch (K. Zaman and J. Panda)
  - Includes "blind test" prediction of transonic nozzle resonance shift versus Mach number
  - Excellent agreement
    - Screech frequencies at several jet Mach numbers
    - Shock cell structure
    - Sound pressure levels except near nozzle tip


Pressure isosurfaces from CE/SE nozzle computations showing 3D structure and shock cell resolution


Comparison CE/SE frequency and sound pressure level computations (solid symbol) with experimental data (open symbol)

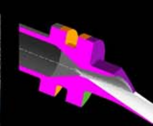
Unsteady Flows 2–D/3–D Aeroacoustics

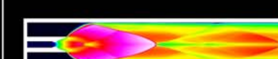
Core Experimental and Analysis Capabilities

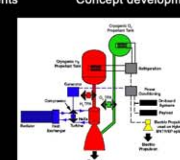
Example: Ducted Rocket Performance Assessment


Engine system experiments


Component experiments

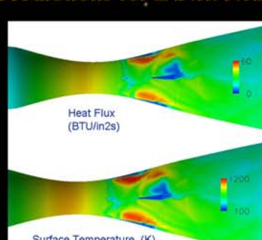

Concept development


2–D/Axi system evaluation using CFD


Engine cycle/system studies

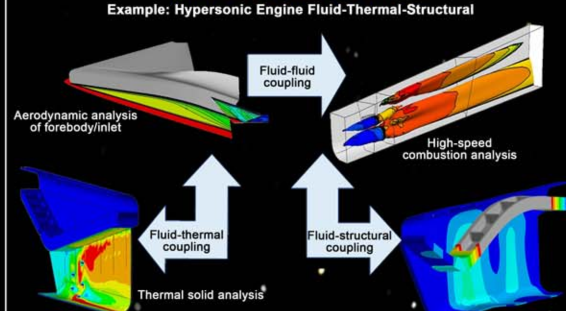
Experimental/Analysis Foundation

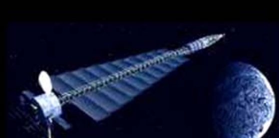
Surface Heat Flux and Temperature Predictions for LANTR Nozzle



Multidisciplinary Analysis

Example: Hypersonic Engine Fluid-Thermal-Structural





Multidisciplinary Analysis

National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

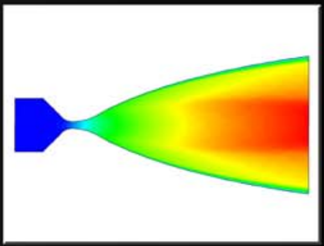
NASA Glenn Nozzle Design, Analysis, and Testing

- Performs computational and experimental research on nozzles including complex variable geometry, highly integrated nozzle and vehicle configurations
- Provides enabling capabilities to the U.S. aerospace community by performing research and developing technology that focuses on nozzles
- Works in partnership with NASA's Aerospace Technology Program Offices to maintain U.S. technology leadership
- Interfaces with other NASA centers, government agencies, industry, academia, and other customers to transfer nozzle technology for commercial and military applications

Design

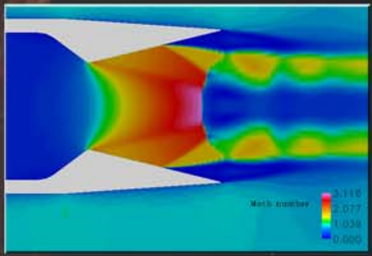
- Capabilities for developing optimal nozzle designs for applications ranging from subsonic aircraft to spacecraft rockets

Isentropic aircraft nozzles



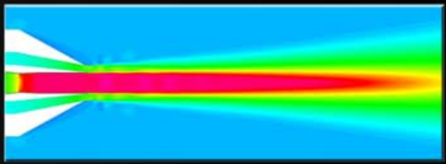
Rocket MOC design

Computational Fluid Dynamics (CFD) Analysis



Off-design analysis

- Primary code developers (with U.S. Air Force Arnold Engineering Develop ment Center and Boeing) of the Wind-US flow solver
- Extensive experience providing high-fidelity flow simulations of exhaust nozzle systems for all aerospace applications
- Experts in nozzle performance and plume calculations

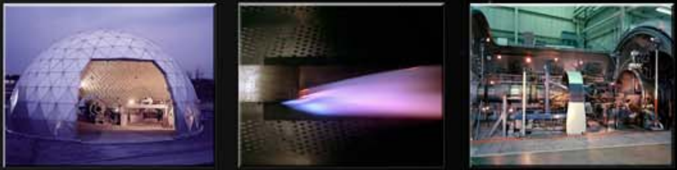


Turbulent jet plume CFD

Experimental Testing

- A broad range of world class testing facilities:
  - — Advanced Nozzle Test Facility
  - — Propulsion Systems Laboratory (PSL)
  - — 9- by 15-Foot Low Speed Wind Tunnel
  - — 8- by 6-Foot Supersonic Wind Tunnel
  - — 10- by 10-Foot Supersonic Wind Tunnel
  - — Nozzle Acoustic Test Rig (NATR)
  - — 20- by 30-Inch Low-Speed Wind Tunnel
  - — Free Jet Facility
  - — Hypersonic Test Facility (Plum Brook)
- State of the art force and flow measurement capabilities
- Expert personnel with the international reputation for excellence in experimental nozzle research and development

Small-scale rig testing



Large-scale testing in the NATR, 8- by 6-foot wind tunnel and PSL

Points of Contact:
Nozzle Design and CFD: Nicholas J. Georgiadis (216-433-3958), James R. DeBonis (216-433-6581).
Nozzle Testing: Albert L. Johns (216-433-3972), John D. Wolter (216-433-3941),
Raymond S. Castner (216-433-5657), Khairul B. Zaman (216-433-5888)

National Aeronautics and
Space Administration

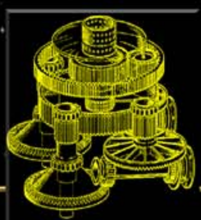
Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

GRC Structures Division Core Capabilities Enable Lightweight, Durable, Reliable, and Safe Structural Systems for Space Exploration

Combustion liners
Cryogenic tanks
Rotor systems
Lubricants
Oil-free bearings
Injectors
Aeroshells
Habitats

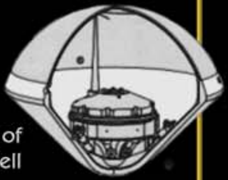
Nozzles
Biomimetic systems
Mechanical drives
High- and low-temperature seals
Magnetic bearings
Flywheels
High-power electric motors



Advanced Drive Systems

Fault Tolerant Foil Bearings

Advanced Thermal Barrier Seals



Analysis and Testing of Deep Space Ceramic Aeroshell

Crack Growth Modeling for Shuttle SSME

Actively Controlled Variable Area Nozzle

Core Capabilities

- Materials modeling and characterization
- Failure and damage growth
- Fatigue and fracture
- Static, dynamic, and aeroelastic response
- Life prediction and assurance
- Residual strength
- High-energy impact response
- High-temperature and cryogenic seal technologies
- Drive systems
- Structural and mechanical system health prognostics
- Surface science and coatings
- Lubricant chemistry
- Mechanisms
- Nanomaterials
- Computational materials
- Reliability-based design and analysis methods

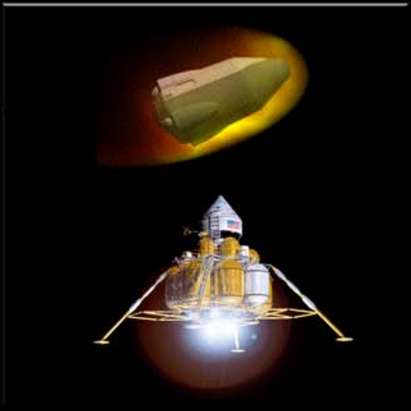
National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

GRC Structures Division Technologies for Crew Transfer

GRC expertise in life prediction, advanced structures, mechanisms, seals, bearings and tribology, and structural mechanics enable the development of durable and reliable crew transfer systems for space exploration.



Launch Vehicles, Landers, CEV Modules, and Orbit-to-Orbit, Earth Return Systems

Life Prediction

Accurate thermomechanical deformation and life modeling given complex multiaxial loading and harsh environments

Deformation and life modeling of rocket nozzles

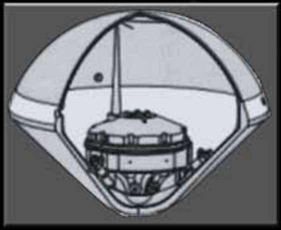
Advanced Thermal Barrier Technologies

High-temperature thermal barrier seal technologies for launch vehicle motors

5500 °F carbon fiber thermal barrier (NASA 2004 Invention of Year)

Structural Mechanics and Analysis

Lifing and durability predictions of complex structural components



Analysis and testing of Deep Space 2 ceramic aeroshell

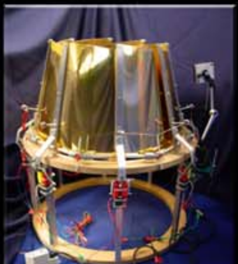
Oil-Free Bearings

Foil bearings for rotating components in nuclear propulsion systems

Demonstration of high-temperature foil bearing

Advanced Structures

Smart structures technologies for lightweight integrated systems



Prototype variable area nozzle with shape memory alloy actuators

Structural Seals

Durable seals for ablative and control surfaces on reentry vehicles

World-class seal test facilities and expertise for all seal and thermal barrier applications

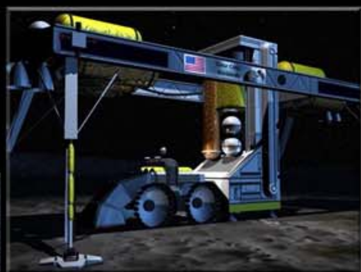
National Aeronautics and
Space Administration

Glenn Research Center
Exploration Systems

Explore. Discover. Understand.

GRC Structures Division Technologies for Surface Operations

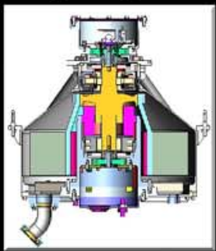
GRC expertise in life prediction technologies, ballistic impact, mechanisms, seals, and tribology enable the development of durable and reliable surface structures and facilities for space exploration.



Habitats, Storage Facilities, Mobility Vehicles, Power Storage, and Mining Vehicles

Life Predictions Technologies
Probabilistic life modeling of flexible structures for habitats, telecommunications, storage facilities, and power-generation facilities

Kinetic Energy Storage
Advanced magnetic bearing and flywheel technologies for efficient and affordable energy storage

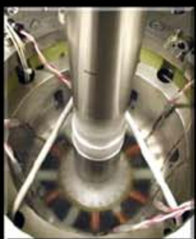


High-energy density flywheel (35.5 W-hr/kg)

Ballistic Impact
Experimental and computational simulation of micrometeor ballistic impact dynamics for large space structures and habitats

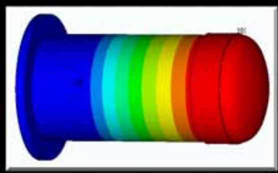
World-class ballistics lab and modeling expertise

High-Energy Cryogenic Motors
Highly efficient motor technology for rover drive system and power drilling equipment



High power density liquid nitrogen motor demonstrated

Life Predictions Technologies
Creep life modeling and testing

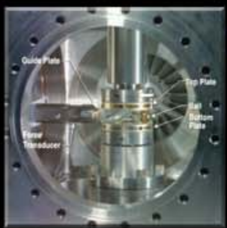


Accelerated creep testing of stirling radio-isotope generator

Habitat Seals
Advanced technologies for durable, long-lasting habitat seals

World-class seals test facilities and expertise

Advanced Lubrication
World-class tribology technologies for long-term lubrication under extreme environmental conditions (e.g., to 40 K at lunar poles)



Spiral orbit tribometer for accelerated lubricant life testing at actual conditions

Advanced Mechanisms
Advanced mechanical power transmission technologies for lightweight and durable drive systems, drilling mechanisms, and actuators

Advanced face gear technology for durable, lightweight mechanical power transmission

National Aeronautics and Space Administration

Glenn Research Center
Exploration Systems

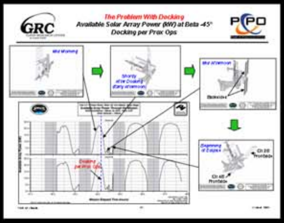
Explore. Discover. Understand.

Systems Analysis

Power Systems Analysis

Two-decade heritage in power systems analyses, including developing the detailed performance model of the International Space Station electrical power system SPACE code (System Power Analysis for Capability Evaluation). SPACE was 2003 runner-up for NASA Software of the Year Award.

- Currently conducting Exploration Systems Mission Directorate—requested conceptual design studies
- Analyses of various International Space Station mission profiles with SPACE code



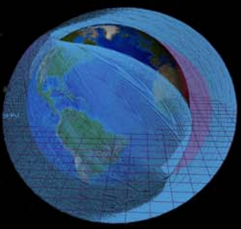
- Developed Hybrid Electric Vehicle Analyses (HEVA) code—an interactive, menu-driven computer program which models the performance of an automotive vehicle, especially that of a hybrid whose motive power comes from an energy storage device

- Reliability and maintainability modeling with ACARA (availability, cost, and resource allocation), a program for analyzing availability, lifecycle cost (LCC), and resource scheduling for a system that undergoes periodic repair
- Brayton cycle analyses for Solar Dynamic Flight Demonstration Project

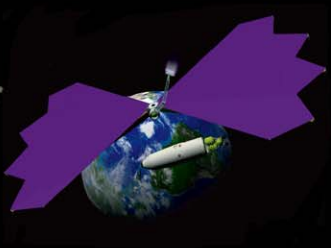
Mission Analysis

In-Space Analysis

- Trajectory Optimization
  - –LEO, HEO, and Interplanetary
  - –Low-thrust, high-thrust, and "hybrid" systems
  - –System modeling
  - –Multi-body dynamics
  - –Control law development
  - –Vehicle sizing and layout
  - –Packaging/deployment



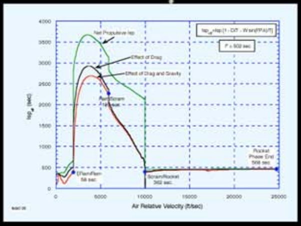
Low Thrust Earth Spiral Out Trajectory

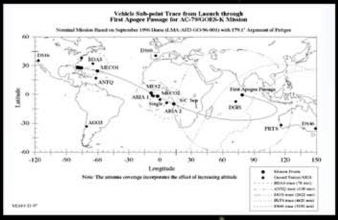


Solar Electric Upper Stage

Earth-to-Orbit Analysis

- Trajectory optimization
  - –Advance propulsion concept assessments
    - –RBC and TBC
  - –Booster upper-stage trades
  - –Vehicle sizing
  - –Aero-dynamics and trim analysis





Advanced Tool Development

- ETO and in-space trajectory
  - –High fidelity N-body simulation
  - –Low-thrust trajectory analysis
  - –Vehicle weights and sizing
  - –Collaborative engineering
  - –Multidisciplinary optimization

GLIDE
Global Integrated Design Element

Power Systems Analysis Point of Contact:
Bruce Manners • 216–433–8341 • Bruce.A.Manners@nasa.gov
Mission Analysis Point of Contact:
Glen Horvat • 216–977–7062 • Glen.M.Horvat@nasa.gov

Systems Analysis Division Chief, Timothy Wickenheiser, 216–977–7111
Timothy.A.Wickenheiser@nasa.gov